

THE DEVELOPMENT OF BALLOON-BORNE TELEMETERING EQUIP-
MENT FOR THE MEASUREMENT OF OZONE CONCENTRATION IN
THE UPPER ATMOSPHERE

Thesis

submitted by

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for the degree of

Doctor of Philosophy

University of Edinburgh,

May, 1954.



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CHAPTER I

INTRODUCTION

(a) The Discovery of Ozone in the Atmosphere.

The sun's spectrum, as obtained using a spectrograph on the surface of the earth, does not contain wavelengths shorter than about 2900 Å. As early as 1878 Cornu concluded that this must be due to some constituent of the earth's atmosphere absorbing the shorter wavelengths which must come from the sun if this behaves as a black body at a temperature of 6000°K. When Hartley (1881) discovered that ozone has very strong absorption bands centred at 2550 Å, he suggested that this gas was the absorbing agent. A most striking proof of this hypothesis was furnished when Fowler and Strutt (1917) obtained photographs of the sun's spectrum showing very clearly the characteristic bands found by Hartley and named after him. The fact that the wavelengths less than 2900 Å in the sun's spectrum could not be obtained when the spectrographs were exposed on mountain-tops indicated that the ozone must be high up in the atmosphere. Measurements later showed that the ozone existed principally in a layer about 25 kilometres above the surface of the earth, the total amount of ozone in the atmosphere being

equivalent to a layer only 3 mm. thick at S.T.P.

(The total amount of ozone in the atmosphere is conveniently measured as the thickness a layer of pure ozone would have if it contained all the ozone in the atmosphere at S.T.P. Similarly the ozone content of air at any height in the atmosphere is often expressed as the thickness of a layer of pure ozone at S.T.P. in which is contained all the ozone in 1 Km. of air at that height).

(b) Some Properties of Ozone and its Importance in the Atmosphere.

Ozone was first recognised as being distinct from oxygen by Schönbein in 1840 and its properties are in agreement with the formula O_3 . Pure ozone, which is difficult to obtain, melts at $-250^{\circ}C$ and boils at $-112^{\circ}C$. The exothermic reversion of O_3 to O_2 often proceeds with explosive violence. Ozone contained in a glass vessel decomposes, the rate of decomposition increasing with temperature. It is a very powerful oxidising agent and, in particular, liberates iodine from a solution of potassium iodide: this forms the basis of most chemical methods of determining ozone concentrations. Care has to be exercised in these methods since substances such as chlorine, bromine,

hydrogen peroxide and the oxides of nitrogen also have this effect.

The property of ozone which makes the gas such an important constituent of the atmosphere despite its small amount, is its strong absorption of light. In the ultraviolet region of the spectrum the principal band system is the Hartley one. The bands have a diffuse structure against a background of continuous absorption and extend from 2100 A to 3200 A. Investigations by Ny Tsi-Zé and Choong Shin-Piaw (1932) show an absorption coefficient of 140 cm^{-1} at 2550 A. There are two other band systems in the ultraviolet, the Shaver bands and the Huggins bands (Huggins 1890). These overlap the Hartley bands but have relatively small absorption coefficients.

In the visible region there is the Chappuis diffuse band system extending from 4500 A to 6500 A, the absorption coefficients being very small (Colange, 1927).

There are three band systems in the infra-red lying around 4.7μ , 9.6μ and 14.1μ with respective absorption coefficients of 0.13, 0.22, and 0.70 cm^{-1} . (Hettner et al., 1934).

Ozone in the atmosphere is important biologically since, without it, the sun's ultraviolet light would reach the earth and make life, as we know it,

impossible. The long-term variations in ozone content causing fluctuations in the intensity of ultraviolet light reaching the ground may be responsible for changes in animal and plant life.

The absorption by ozone both in the ultraviolet and infra-red regions coupled with its position high up in the atmosphere combine to make it an extremely important factor in the physics of the atmosphere. In fact the ozone must act like a vast heat reservoir and is responsible for the raising of the temperature of the upper regions of the stratosphere around 50 Km. to 300 or 350°K. The strong narrow band at 9.7 μ is important in this connection since it is at a part of the spectrum where both water vapour and carbon dioxide are transparent to the intense outgoing radiation from the earth.

(c) The Measurement of Atmospheric Ozone.

The method still used to determine the total amount of ozone in the atmosphere was first developed by Fabry and Buisson (1921). Using a quartz spectrograph they compared the intensities of two wavelengths in the sun's spectrum for different zenith distances of the sun. The two wavelengths were chosen in the critical region from 3200 A to 2920 A where the

absorption coefficient of ozone changes rapidly and so one wavelength was absorbed much more strongly than the other. Different zenith distances of the sun give rise to different path lengths of the light in the ozone layer and the thickness of this layer can be estimated from the intensity ratio - zenith distance relationship. Dobson and Harrison (1926) took account of scattering by large particles as well as Rayleigh scattering to improve the determination of the total ozone content.

A great advance was made when Dobson (1931) introduced his photoelectric apparatus. Due to its sensitivity this instrument could be used even when the sky was overcast and was much quicker to operate. Since it could also be used for intensity measurements on scattered light from the zenith sky, the method of determining the vertical distribution of ozone suggested by Götz (1931) became practicable.

In this method the ratio of the intensities of two wavelengths in sunlight scattered from the zenith sky is measured for different zenith distances of the sun. It can be shown that for each position of the sun and for each wavelength, there is a region in the atmosphere where most of the light is scattered. The height of this region is greater for the smaller

wavelengths and for low positions of the sun. The effect of this is that the ratio of the intensity of the shorter wavelength to that of the longer wavelength, $I_{\lambda}/I_{\lambda'}$, decreases with increasing zenith distance, z , of the sun until there comes a time very near sunset, or sunrise, when most of the light of wavelength λ is scattered above the ozone layer whereas the light of wavelength λ' is still being scattered in the ozone region. This means that $I_{\lambda'}$ still diminishes rapidly with increasing z but I_{λ} is not affected so much and the net result is that the ratio $I_{\lambda}/I_{\lambda'}$ begins to increase again as z approaches 90° . There is as yet no general method of analysing the curves of $-\log I_{\lambda}/I_{\lambda'}$ against z^4 , which are called 'Uhmkehr Curves' in order to obtain the vertical distribution of ozone. Approximate methods have to be used (Götz, Meetham and Dobson, 1934) but work is in progress with the object of improving the accuracy of this technique by considering the effects of secondary and multiple scattering (Walton, 1952). Much more accurate 'uhmkehr' curves are now being obtained, using the latest version of the Dobson spectrophotometer (Normand and Kay, 1952) which incorporates a photomultiplier instead of the sodium photocell, thus making the instrument still more sensitive and

allowing observations to be made by moonlight.

In Western Europe the older type of instrument is being replaced by this modernised version at about twenty stations which form an ozone spectrophotometer network organised by the International Ozone Commission under Sir Charles Normand, Professor G.M.B. Dobson and Dr. R.H. Kay.

The vertical distribution of ozone in the atmosphere has been determined in several other ways. The first direct measurements were made by E. and V.H. Regener (1934) using an automatic quartz spectrograph carried by balloon. A series of photographs of the sun's spectrum was taken, showing the gradual extension towards the ultraviolet end as the apparatus penetrated into the ozone layer. This technique has recently been used in the U.S.A. in rockets developed from the German V-2 weapon (Johnson et al., 1952) and balloon flights are still being made by V.H. Regener (1951) in New Mexico.

Ozone measurements were made during the flight of the balloon Explorer II, using both a spectrographic method and a chemical method whereby sampling bottles were opened at different heights and their contents later analysed (O'Brien et al., 1935). The chemical determination of ozone concentration has been improved

notably by Ehmert (1952) who has used it to compile much information about the ozone content of air layers near the ground. He also made measurements on a few occasions with the apparatus in an aeroplane (Ehmert, 1941). An apparatus based on that of Ehmert has been used by Dr. R.H. Kay in collaboration with the Meteorological Research Flight at Farnborough to measure the variation of ozone concentration with height up to altitudes of 12 Km.

During an eclipse of the moon the geometrical shadow of the earth on the moon is faintly illuminated by light refracted in the earth's atmosphere on its way from the sun to the moon. This light is mostly at the red end of the spectrum and is thus affected by the Chappuis absorption bands of ozone. Paetzold (1950) was able to infer the height distribution of the absorbing layer from the intensity distribution existing perpendicular to the edge of the earth's shadow. At first this was only possible for the layers higher than the ozone maximum but further development (Paetzold, 1951) produced a comparatively simple method of obtaining the ozone distribution for heights of from 10 Km. to 40 Km. Of course, the eclipses are infrequent occurrences and the sky must be clear, but this method has the advantage of being

able to produce distributions for latitudes which are difficult to investigate by any other means.

Much work has been done towards evolving the ozone distribution from purely theoretical considerations. This is difficult due to the many factors involved -- the photosynthesis of ozone, the destruction of ozone, the density of the atmosphere, horizontal and vertical transport of air masses in the atmosphere, etc. The researches of Chapman (1930), Mecke (1931) and Wulf and Demming (1936) showed that photochemical considerations must form the basis of the explanation of the main features of the stratification of ozone and they were able to obtain theoretical curves with the ozone maximum close to the observed value of 23 Km. Some of the physical constants entering the calculations are not yet known very accurately and this is hampering the work to some extent.

(d) Results and their Relation to Meteorological Conditions.

Measurements over more than twenty years by the above methods have resulted in the discovery of the variation of the ozone content of the atmosphere with season, latitude and weather conditions. Dobson (1930) showed that, in general, the ozone content has a maximum in spring and a minimum in autumn in

both the hemispheres, the annual variation being greatest in high latitudes and least at the equator. The total amount of ozone in the atmosphere varies between equivalent thicknesses of 1.5 mm. and 4.5 mm. at S.T.P., polar air having a high ozone content and equatorial air a low content. Attempts have been made to explain the temperature variations in the stratosphere and the variations of the height of the tropopause in terms of ozone distribution (Dobson et al., 1946; Langlo, 1952). The annual mean ozone content may vary considerably from year to year and Langlo (1952) shows results of observations at three stations over a ten year period. The changes in the annual mean may amount to 15% of the annual mean amount of ozone. There is, moreover, a clear correlation between the changes at the three stations but this does not seem to be due to changes in the ultra-violet radiation from the sun as might be supposed at first glance. It is thought that account must be taken of the general circulation of the atmosphere in order to explain these ozone variations. According to Götz and Zünti (1936) there is no valid relationship between the sunspot period and variations in ozone amount.

It has been found that the ozone value is high in cyclonic systems and low in anticyclonic systems.

Fronts which extend up into the stratosphere are accompanied by changes in ozone content as they pass the observing station. A drop in ozone value is associated with the passage of a warm front and, in fact, this may be the first indication of the approach of the front. Conversely a rise in ozone value accompanies a cold front. An occluded front may occasion either a rise or a fall in ozone value depending on its make-up. A rise of 2 mm. in the ozone content was measured at Oxford (Dobson et al., 1946) when a thunderstorm passed overhead.

At present it is not possible to build up a complete picture of the causes of the variations of atmospheric ozone but the general outline appears to be as follows. The ozone is mainly formed at around 30 Km. where the ultraviolet light ($\lambda \leq 2420 \text{ A}$) from the sun has not yet been absorbed and the density of the atmosphere is sufficiently great to allow a reasonable number of the necessary three-body processes. The region of the atmosphere above 35 Km. can be regarded as being in a state of photochemical equilibrium with the sun's radiation. The ozone content of this region is relatively small and is approximately independent of latitude and season. From 35 Km. to 20 Km. there is a transitional zone between states of equilibrium and non-equilibrium, with ozone transported

from above accumulating and only decaying very slowly since the sun's ultraviolet light has been absorbed in the higher layers. Below 20 Km. the ozone cannot be in photochemical equilibrium and, in the lowest layers near the ground, ozone is destroyed by contact with organic matter and substances such as sulphur dioxide.

The major changes in ozone content take place below 20 Km. and these cause the observed day to day changes in the total amount of ozone. The seasonal variations and the distribution with latitude may be explained by changes in the transitional layer caused by changes in the general circulation embodying seasonal changes in the vertical air motions and in the advection of air masses with different ozone content.

For a clearer understanding of the situation frequent measurements of the vertical distribution of ozone are required. In such measurements which have been made up till now, very interesting results have been obtained (E. Regener, 1952) showing a relation between the form of the vertical distribution and the source of the air mass concerned. A curve with a sharp maximum, such as predicted by photochemical theory, has been found to be associated with equatorial air masses of low ozone content. Also deformed

curves obtained mostly in spring were related to polar air masses with a high ozone content.

The work described here was undertaken with a view to developing an instrument which could be used for regular direct measurements of the variation of ozone content with height in the atmosphere. It was hoped that this might eventually supply the necessary data on how the vertical distribution depended on season, latitude and weather conditions.

The apparatus was designed to be carried by balloon and to telemeter the measurements to ground while in flight, thus making possible the compilation of a distribution curve while the flight was in progress and independently of the instrument being recovered. It was realised that this instrument might be useful for the daily weather service if it could be made as simple, reliable and inexpensive as possible.

CHAPTER 2.

THE METHOD ADOPTED FOR OZONE MEASUREMENT

There were two possible methods for the determination of ozone concentration at different heights in the atmosphere. One, a chemical method, is based on oxidation by ozone of a neutral solution of potassium iodide: the other, a spectrophotometric method, measures the strong absorption of ultraviolet light by ozone utilising a photocell and amplifier. Of the two, the latter is more suitable for incorporation in an apparatus telemetering measurements immediately to the ground. It also has the advantage of being specific to ozone whereas the chemical method responds to the oxides of nitrogen which are present in the atmosphere in small quantities.

Two types of ozone radio sonde have so far been constructed (Coblentz and Stair, 1939; Stranz, 1948). Both measured the variation in intensity of certain wavelengths in the sun's spectrum as they were carried aloft by balloon. The wavelengths were chosen near the ultraviolet cut-off which is caused by the absorption of atmospheric ozone. This means that such an instrument measures, not the varying concentration of ozone as it ascends, but the different total amounts of ozone above it during the ascent. This tends to make the method rather insensitive since the

vertical distribution must be deduced from the differences between the total amount of ozone as measured from the ground and the amounts of ozone still remaining above the instrument during its ascent.

Other difficulties in this method are in the instrumentation. Some means is required of separating out specific wavelengths. In order that account may be taken of scattering in the atmosphere, two wavelengths are usually chosen -- one just inside and the other just outside the absorption band of ozone. This proves to be an expensive item if it is to be at all selective without seriously cutting down the intensity of the required wavelengths. Also some mechanical arrangement for providing an a.c. signal must be incorporated to avoid the use of a d.c. amplifier with all its inherent instability and shift.

In view of these considerations it was decided to include a source of ultraviolet light in the instrument and, during an ascent, to measure the intensity of this light after it had traversed a fixed distance in the surrounding air. With this type of apparatus it would be possible to measure the actual ozone concentration as a function of height either by day or by night.

A low-power lamp emitting the mercury resonance line at 2537 A was seen to be suitable since this line

is at the maximum of the ozone absorption band in the ultraviolet. Many of the other disadvantages of the method described above would also be eliminated if the lamp were made to emit pulses of light. This simple production of an a.c. signal meant that a straightforward R-C coupled amplifier could be used which would only amplify signals from the photocell caused by rapid changes of light intensity. Thus only pulses due to the lamp would be accepted and stray light would be ineffective unless its intensity were changing violently. A great saving in power would also be effected since the lamp would only be drawing current for a small fraction of the time.

A method by which a varying absorption could be detected and measured had then to be considered. The following table gives the fractional changes in intensity of light of wavelength 2537 Å as it traverses different path lengths in air containing different amounts of ozone. This table is based on the absorption coefficient of ozone, α , having the value 140 cm^{-1} for the wavelength 2537 Å. Thus $I = I_0 \times 10^{-\alpha d}$ where I is the reduced intensity of light of initial intensity I_0 , after it has passed through a layer of ozone d cm. thick at S.T.P.

The range of ozone content 0.005 cm./Km. to

Path Length in air (metres)	Ozone Content = 0.005 cm./Km.		Ozone Content = 0.02 cm./Km.		Change in I/I_0 %	Corresponding change in a 30 volt signal from photocell amplifier (volts)
	d (cm.)	I/I_0 %	d (cm.)	I/I_0 %		
5	2.5×10^{-5}	99.2	10^{-4}	96.8	2.4	0.7
10	5×10^{-5}	98.4	2×10^{-4}	93.8	4.6	1.4
20	10^{-4}	96.8	4×10^{-4}	87.9	8.9	2.7
50	2.5×10^{-4}	92.3	10^{-3}	72.4	19.9	6.0

0.02 cm./Km. is roughly that which prevails in the atmosphere and thus the percentage variations are those which might be expected during an ascent. Obviously the greater the path length which could be used, the better would be the sensitivity, but this length is limited by such factors as lamp output, reflectivity of mirrors in the ultraviolet, transmission of windows and filters and amplifier gain. It was decided to make the absorption path as long as possible and to maintain sensitivity by having an accurate telemetering system. Taking into account the performance of radio valves suitable for inclusion in the airborne equipment and H.T. voltages likely to be available, the amplitude of the output pulse from the photocell amplifier, corresponding to the flash of light from the lamp, was going to be of the order of 30 volts. The final column of the above table is based on this figure and indicates the voltage range which would have to be telemetered to the ground and from which the ozone distribution would have to be calculated.

Some means of correcting for any drift in lamp output or amplifier gain would have to be built into the apparatus. The best way of doing this would be to have a second path for the light in which there was no absorption by ozone. Practically this could be realised

by making this path very short. To avoid using a second photocell it could be arranged for the light intensities from the two paths to be measured alternately by the same photocell.

It was known (Rössler and Schönherr, 1938) that a low pressure lamp could be made very efficient in its production of the 2537 A line relative to other lines in the mercury spectrum, but for greater sensitivity, it would be desirable to isolate the 2537 A line as completely as possible. This could be done very effectively by means of a Transpex filter which, for practical purposes, could be regarded as opaque to the 2537 A line and transparent to all other lines. Hence, if the intensity of the light emitted by the lamp were measured with and without Transpex interposed in front of the photocell, the intensity of the 2537 A radiation could be immediately calculated. Incorporating Transpex into each of the two paths would then bring the number of light intensities to be measured to four, namely those

from	{	the long path with Transpex	
	{	" " " without	"
	{	" short " with	"
	{	" " " without	"

The next step was to see if this was a practical proposition. It was arranged that the lamp was pulsed

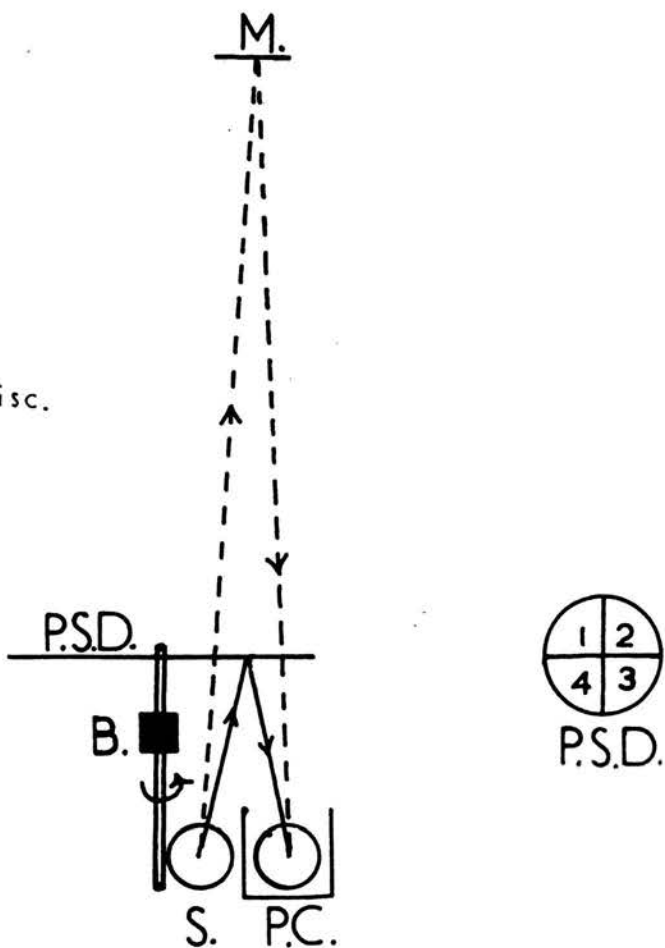
B. = Switch Box.

M. = Mirror.

P.C. = Photocell.

P.S.D. = Path Selector Disc.

S. = Light Source.



P.S.D. Quadrant	1.	Vacant.
"	2.	Transpex.
"	3.	Transpex aluminised on lower surface.
"	4.	" " " upper "

Fig.1.

Outline of the First Scheme

by the closing of a switch and the resultant voltage pulse from the photocell amplifier used to charge up a well-insulated condenser. The value of the voltage on this condenser was measured and then the condenser shorted by the closing of a second switch leaving it ready to receive another voltage pulse. The two switches were actuated by the rotation of a spindle driven by an electric motor. On the same spindle was mounted a path selector disc which gave the four required paths in synchronism with the closing of the switches. (Fig. 1).

For reasons connected with the electronics of the telemetering system, it was essential that both switches should have sharp, clean 'makes' and 'breaks'. Many different types of switches were made and tested. In some, contact was made by wire brushes pressing on the surface of a rotating cylinder of Perspex which had metal contacts embedded in it, flush with the surface. Others embodied a rotating cam which pushed forward a sprung arm and caused two taut platinum wires to come in contact with one another in the form of a cross (+). An attempt was even made to use lightweight relays actuated by sub-miniature thyratrons.

While most of these switches could be made to operate cleanly for a short time, they were all unreliable and needed constant attention and so were by no means suitable for use in a balloon-borne apparatus.

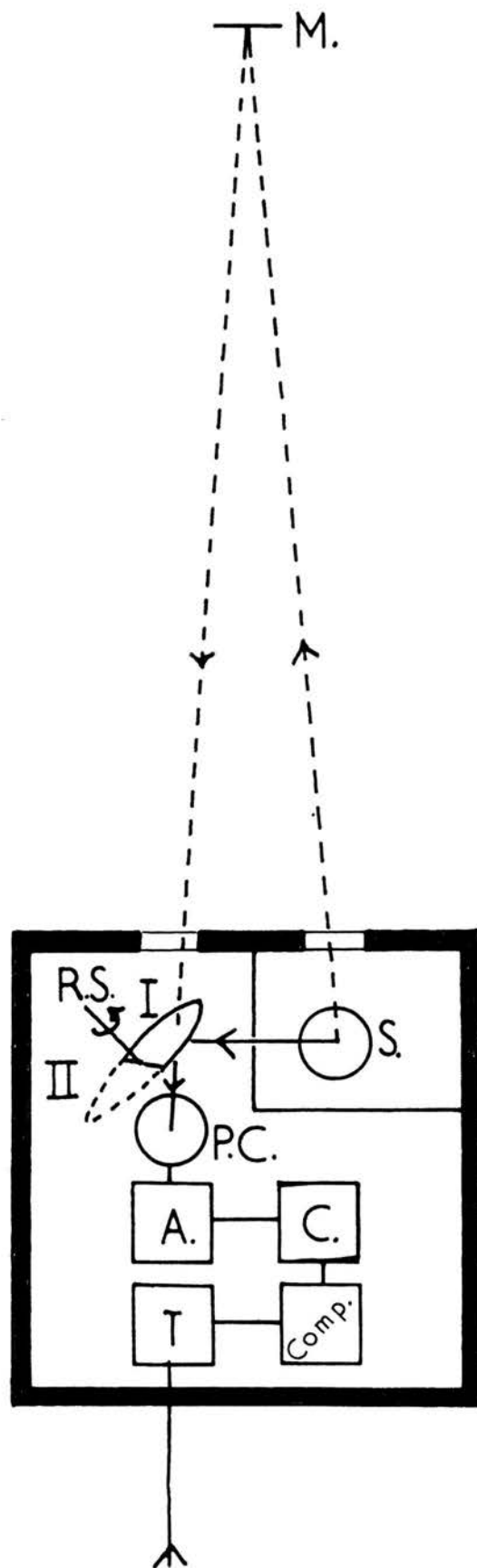


Fig. 2.

To avoid this difficulty, some change in plan was necessary and a useful clue was obtained when it was discovered that the lamp could be made self-pulsing under certain conditions. Following this up, the elimination of the second switch, which discharged the condenser after each intensity measurement, was found to be practicable. The discarding of the switches, however, necessarily entailed the loss of the means of synchronisation between the path selector disc and the flashing of the lamp.

Thereupon it was decided to have a slowly rotating sector and to measure the light intensity over one path for about 30 seconds and then over another for a similar period. At the same time the number of paths was cut down from four to two by dispensing with the Transpex. This made things much simpler from a practical point of view and did not affect the sensitivity of the instrument as a filter was now included which cut out very nearly all the light emitted by the lamp with the exception of that of wavelength 2537 A.

This arrangement was found to be feasible and was adopted in the ozone radio sonde. The mode of operation is shown in Fig. 2. The source of 2537 A radiation, S, flashes and the light is reflected into the photocell, P.C., from the aluminised front surface of a Perspex sector, R.S., in position I. The output of the photocell is fed into the amplifier, A, which produces

a positive voltage pulse and charges up a condenser, C, to a voltage which depends on the intensity of the light falling on the cell. This voltage is accurately measured by the comparator, Comp., and this intelligence sent to the ground by the transmitter, T. In this operation the condenser, C, is automatically discharged and is ready for another measurement. This process goes on at a rate determined by the pulse repetition frequency of the lamp, until the sector, R.S., has moved into position II when the light has now to travel along a 5-metre path to a mirror, M, and back to reach the photocell. This gives a ten metre absorption path which was found to be the maximum obtainable. To attain this length a curved reflector had to be placed behind the lamp and the mirror, M, made up of nine plane mirrors all set at slightly different angles to form a rough approximation to a concave spherical mirror.

Referring back to the table on page 17a, it is seen that a variation of 4.6% is likely in the intensity of the light reaching the photocell from the 10-metre absorption path due to the variation of ozone concentration in the atmosphere. In terms of the voltage on the condenser, C, which is the measurement telemetered to the ground, this corresponds to a variation of 1.4 volts in 30 volts and the telemetering system had to be designed accordingly. An accuracy of 1 part in 1,000 was the original target.

CHAPTER 3

THE AIRBORNE APPARATUS.

(a) The Optical Parts - (i) the light source.

The obvious choice for the type of lamp to be used was one containing mercury vapour and emitting the intense resonance radiation of mercury of wavelength 2537 A which is at the maximum of the absorption spectrum of ozone. Since the power available would be small, the lamp had to be a low pressure one and it was found that a very efficient source of light could be obtained by having a discharge carried by argon or neon gas at a pressure of a few mm. Hg. in a quartz tube containing mercury vapour.

In order to keep the 'striking' voltage of the lamp low while still having a reasonable size of discharge, a rich source of ions was incorporated in the form of a tungsten filament coated with a mixture of barium and strontium sulphates bound together with a cellulose paste. At first the striking voltage of the lamp was further reduced by fitting an auxiliary electrode near the filament. A small discharge could then be continually present between electrode and filament and the main discharge easily initiated by the application of a voltage in the region of 100 volts to the anode.

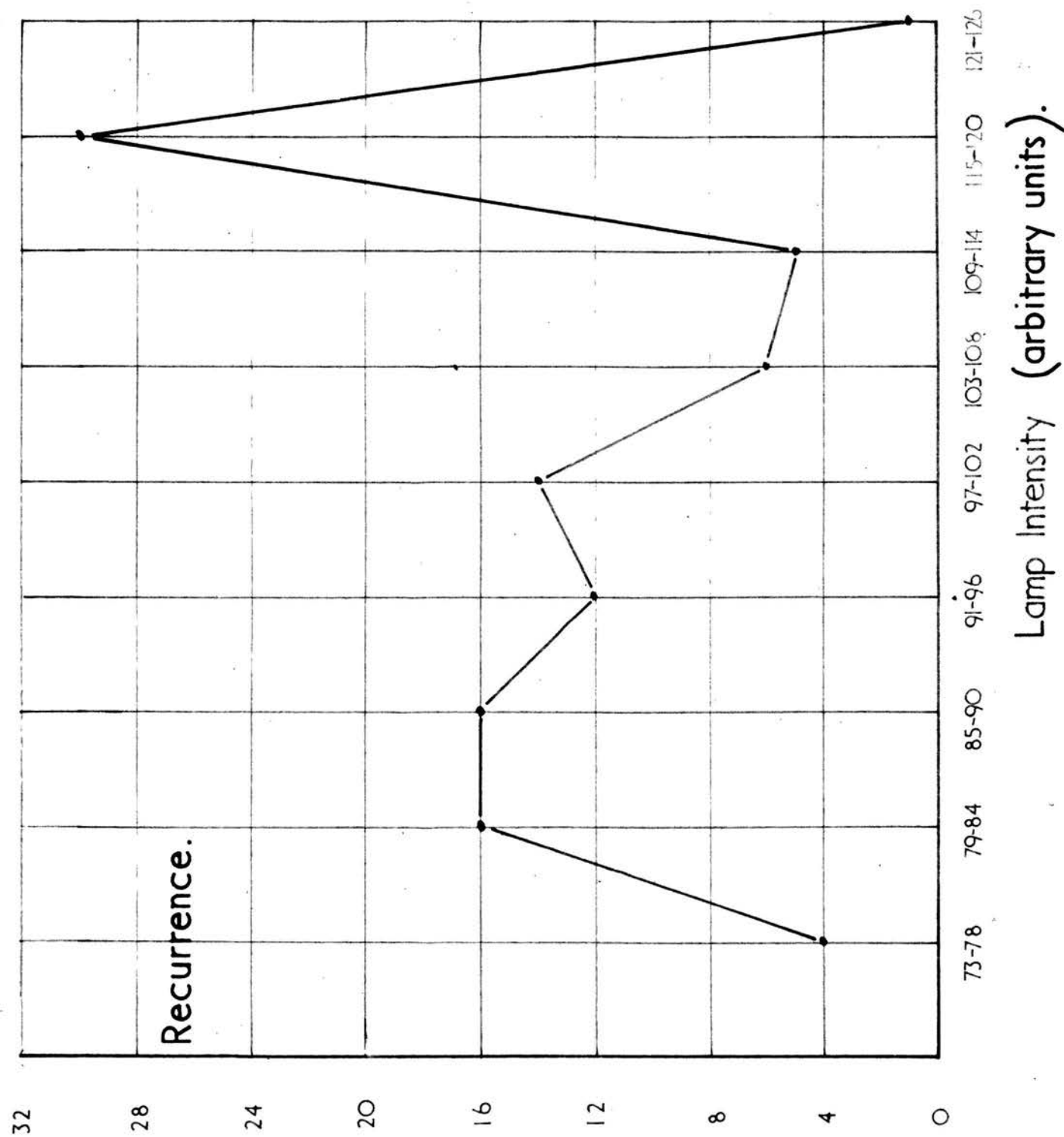


Fig. 3. Histogram of intensity of lamp with auxiliary electrode.

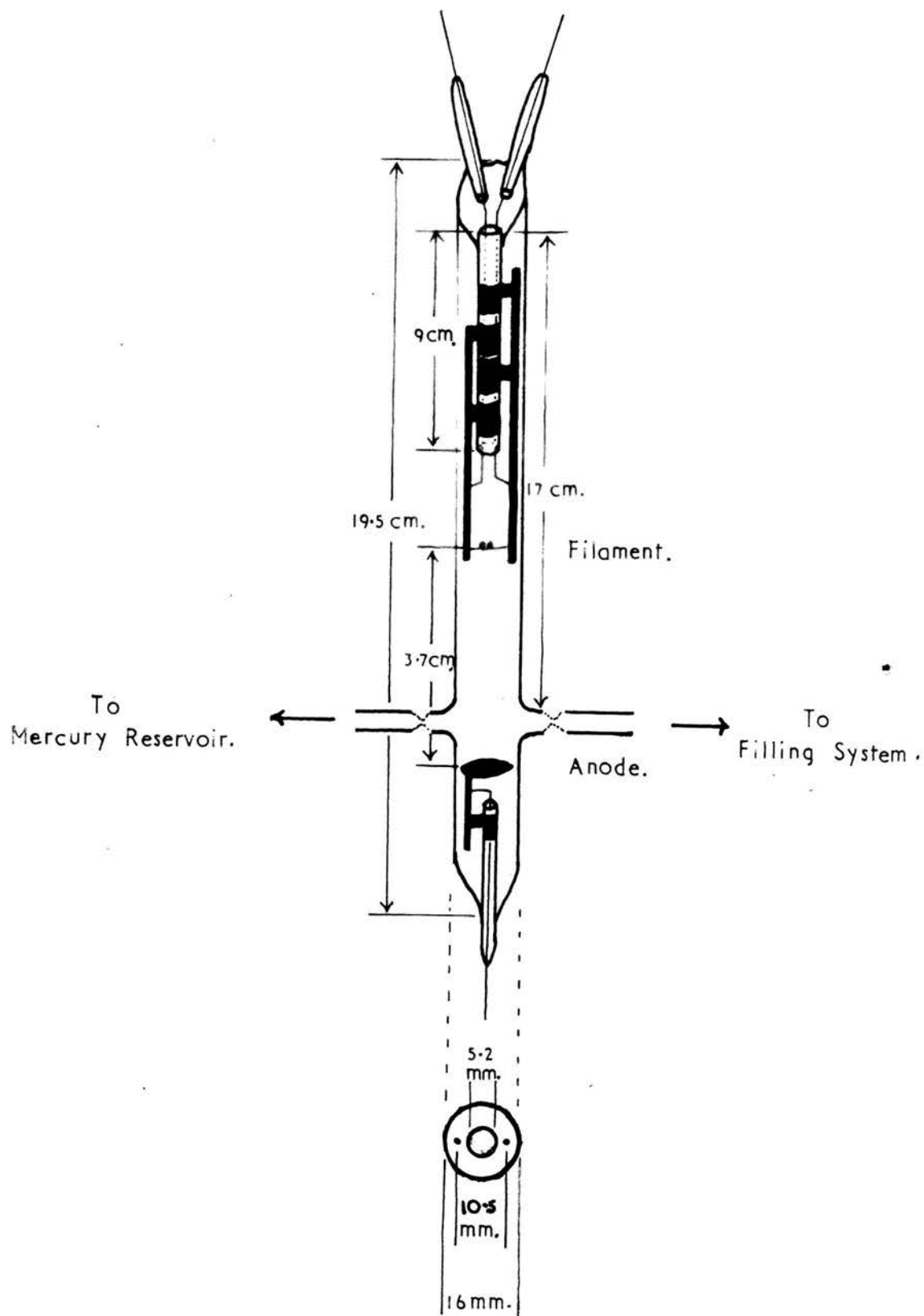


Fig.4.

Experiments with a lamp of this nature showed that the intensity of the light emitted by the lamp was variable, but not in a random manner. In Fig. 3 the intensity of the light given out as the lamp flashed, is plotted against the number of times in which that intensity occurred in 100 measurements. The lamp thus seemed to be emitting several different light intensities. It was concluded that, as the small discharge present all the time was, by nature, oscillatory, the output of the lamp must depend on the state of these oscillations at the instant it was pulsed (Druyvestyn and Penning, 1940). The main discharge was, of course, also oscillatory but, by the application of short, sharp voltage pulses, it was found that the peak light output could be produced before the oscillations had time to build up. These oscillations are in the form of striations in the positive column of the discharge and are not accompanied by an oscillatory current through the tube and so cannot be suppressed by any external circuitry. This meant that the auxiliary electrode had to be discarded and a necessarily greater H.T. voltage used across the tube. With the lamp pulsed by the application of about 200 volts to the anode, the light output was much more constant.

The details of the lamp are given in Fig. 4.

The main tube is of quartz, 16 mm. in external diameter with walls 1.5 mm. thick. The connections to the internal electrodes are effected through commercially-made, molybdenum-quartz seals, the wire being 0.3 mm. thick. The anode is made of out-gassed stainless steel, thickness 0.32 mm., and fits closely inside the tube having a cross-sectional area of 1.2 sq. cm. The anode and filament are supported by nickel rods of thickness 1.5 mm. which are themselves clipped to quartz supports by strips of nickel 0.1 mm. thick. All the connections in these electrode assemblies are made by spot-welding.

The filament is made of tungsten wire. At first, wire of 0.03 mm. diameter was used, consuming 2.1 watts (0.6 A at 3.5 volts). This type of filament burnt out very quickly and was replaced by a more robust one consisting of 0.1 mm. diameter tungsten wire wound in two turns of diameter 1.5 mm. This filament consumed 1.9 watts (1.2 A at 1.6 volts).

One advantage in leaving out the auxiliary electrode was in the easier construction of the discharge tube. Fig. 5 illustrates some of the steps. A piece of quartz tubing, of the same thickness as that used for the main body of the lamp, is shaped as in (i) and two wire seals are fixed into the rounded end (ii) which is then sawn off leaving a

small neck into which a smaller quartz tube (5.2 mm. diameter) is sealed (iii). As shown in Fig. 4, this small quartz tube acts as a support for the nickel rods which, in turn, support the filament. These nickel rods are fixed 10.5 mm. apart and hence the whole filament assembly fits neatly into the lamp body which has an internal diameter of 13 mm. The connecting wires for the filament which come down inside the small tube are insulated from one another by enclosing each in a quartz capillary.

The lamp body is made separately (iv). First a T-junction is made in the tube near the narrowed end which later houses the anode. One arm of the junction is fitted with a cone joint to facilitate the installation of the lamp in a filling system, and the other arm is bent downwards to finish in a small bulb about 6 inches below the end of the main tube. Constrictions are put in both these arms near to the body of the tube in order that they can be easily sealed off when required. A third seal with the anode assembly attached (v) is then slipped down the tube until the quartz neck of the seal fits into the narrowed end of the tube which is then heated to form a vacuum-tight joint. Finally the filament assembly is fitted into the other end of the tube and another joint made.

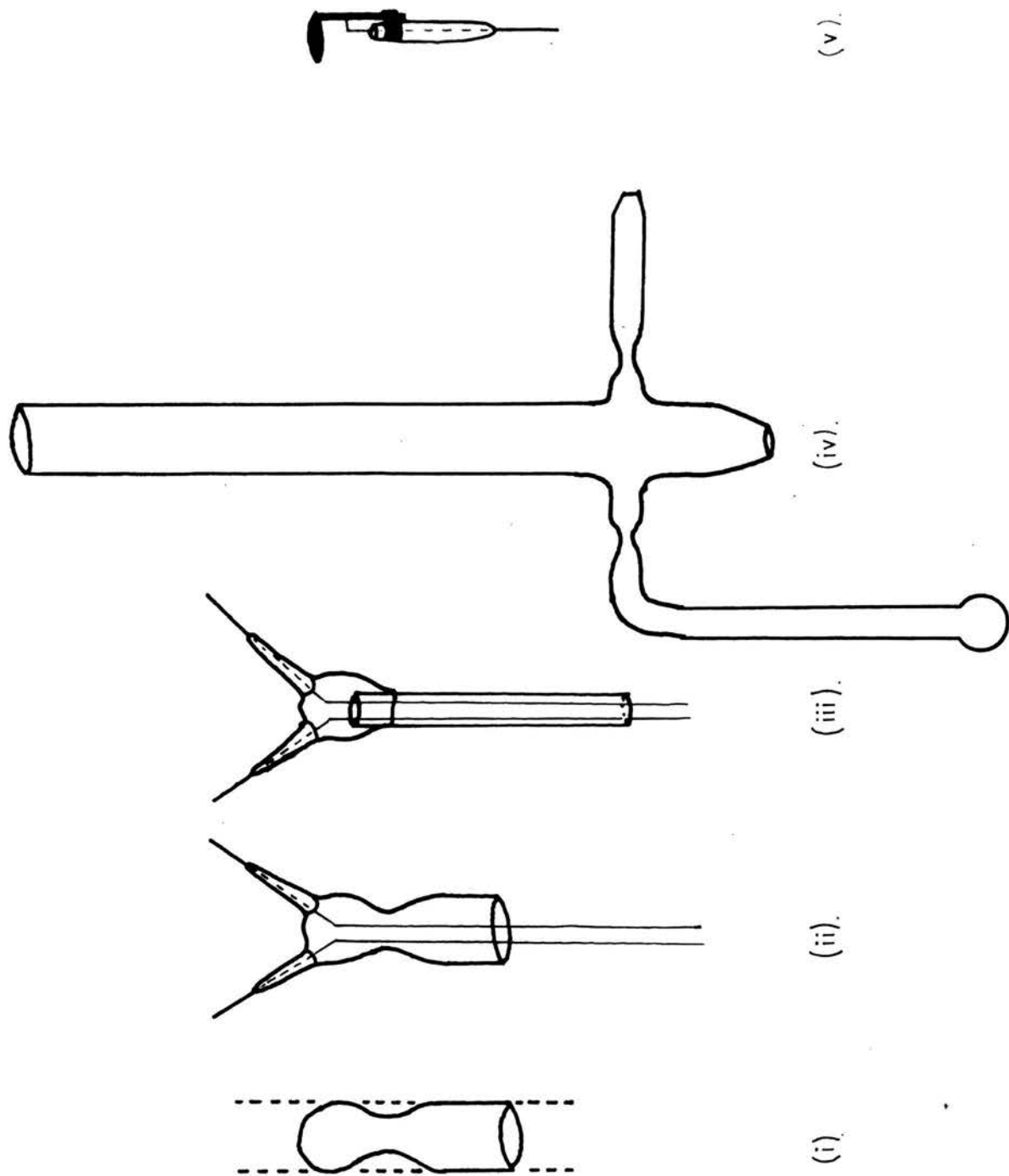


Fig. 5. The Construction of the Lamp.

In all this work an intensely hot flame is required, the one used being an oxy-hydrogen one. This has to be used with great care, not only by reason of itself, but also since the heat has to be kept away as much as possible from vulnerable points such as the electrode assemblies and the connecting wires from the seals. It is of vital importance that no part of the tube is heated unless it is completely clean and free of grease, nor handled after it has been heated until it has returned to room temperature. Failure to observe these latter precautions results in the quartz becoming opaque. Another danger to the transparency of the lamp comes from quartz vapour, released by the tremendous heat of the flame, condensing on some cooler part of the lamp in the form of a fine white powder. However, to someone skilled in working with quartz who follows the sequence of construction detailed above, the building of a lamp presents little difficulty.

The cutting of the quartz tubing is best carried out using a diamond wheel, i.e. a copper disc impregnated with diamond fragments which is rotated at great speed and kept cool by a stream of water.

When construction is complete, a little mercury is poured into the open arm and constrained to flow into the bulb at the end of the tube opposite. The

lamp is then fitted on to the filling line. After ensuring that there are no leaks present, the lamp is out-gassed by heating it to red heat for about six hours while pumping vigorously with a mercury diffusion pump equipped with liquid air trap and backing pump. The heating is carried out in an electric furnace specially built for the purpose. It allows the main tube, containing the metal electrodes, to be heated while the ends of the seals and the bulb containing the mercury can be kept cool. Essentially the furnace consists of an iron tube $2\frac{1}{2}$ inches in internal diameter and 11 inches long built in two interlocking parts which can be fitted, one above and the other below the T-junction of the lamp. Round the iron tube is placed asbestos paper and the heating element, the whole being covered with heat-resisting cement. Power is supplied to the heating resistance through a rheostat, 600 watts being consumed initially until the interior is bright red, whereupon the rheostat is adjusted so as to maintain the furnace in that condition.

The most efficient way of eliminating any remaining contamination is to run a discharge in the lamp while having the liquid air trap in operation. Gas given off raises the striking voltage of the lamp and this provides a sensitive indication of the degree

of outgassing attained. The liquid oxygen trap is always used when the lamp is running in order to avoid any possibility of the filament becoming 'poisoned', but it is not otherwise necessary to keep the trap continually replenished since any contamination -- almost wholly water vapour -- getting back into the metal electrodes will only be in the surface layers and can easily be driven off by a brief heating of the lamp with a gas jet.

When the time comes to seal the lamp off, a little mercury has first to be distilled up into the main tube to lie near the anode seal. The constriction in the side tube leading to the mercury reservoir is then collapsed, using an oxy-hydrogen flame, and the whole side tube carefully eased off, leaving a vacuum-tight seal. The lamp is then filled with argon gas to the required pressure and itself sealed off from the filling line.

To find the optimum filling for the discharge tube, tests were first carried out to determine the relation between gas pressure and light output. The gas used was argon, a glass vessel containing the gas at a high degree of purity being incorporated in the filling system. In Fig. 6 it is seen that the total output of light, as measured by the quartz photocell, increases with the current through the tube and with

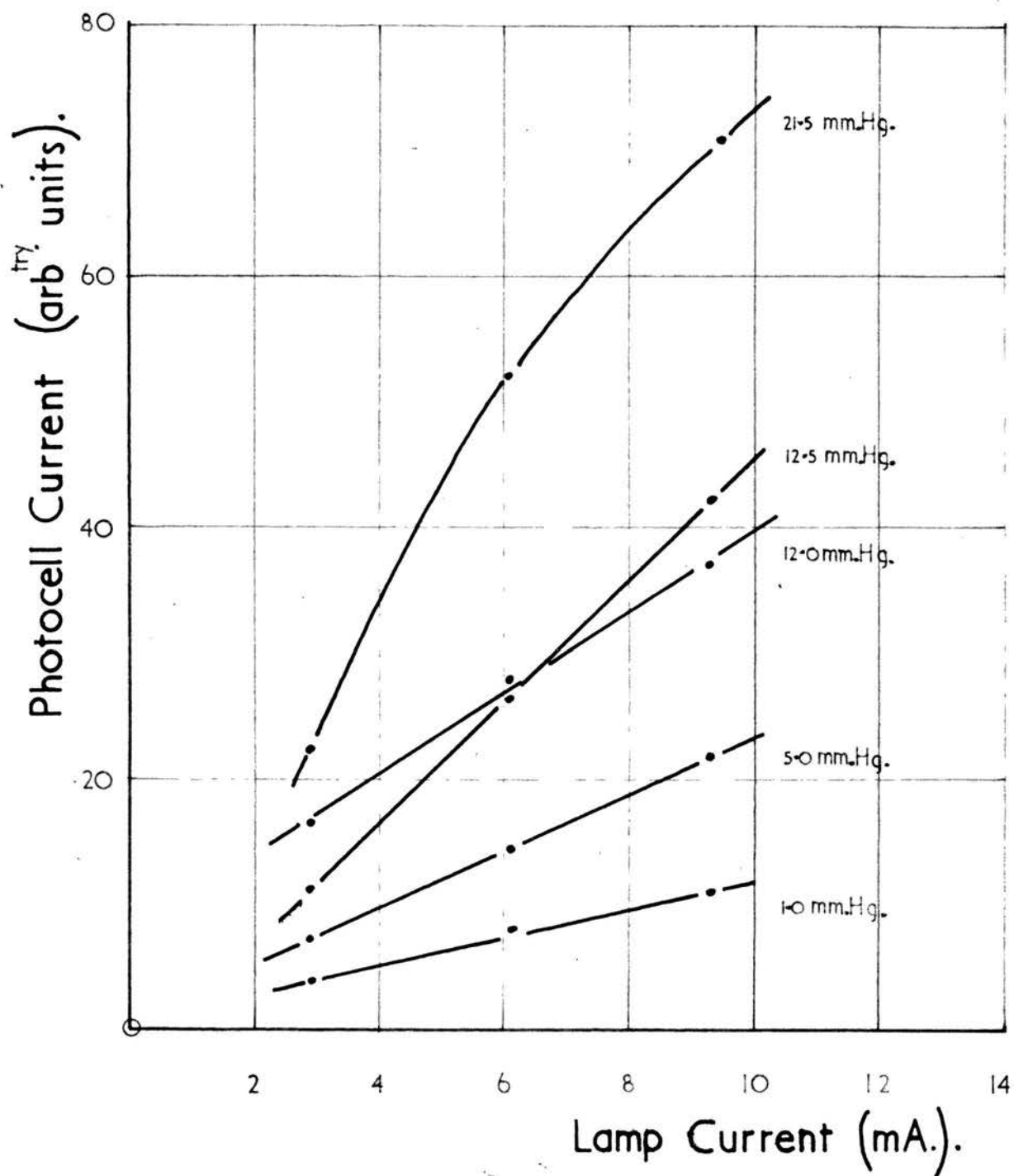
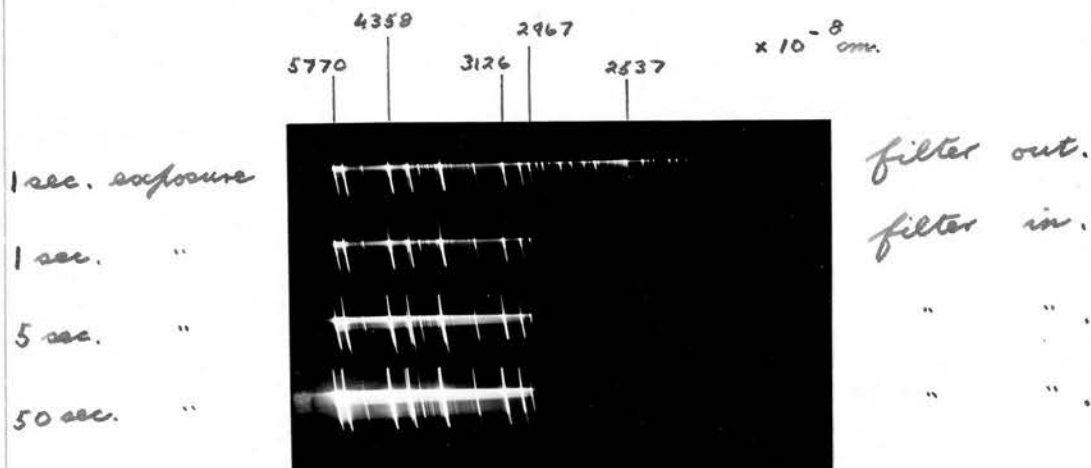


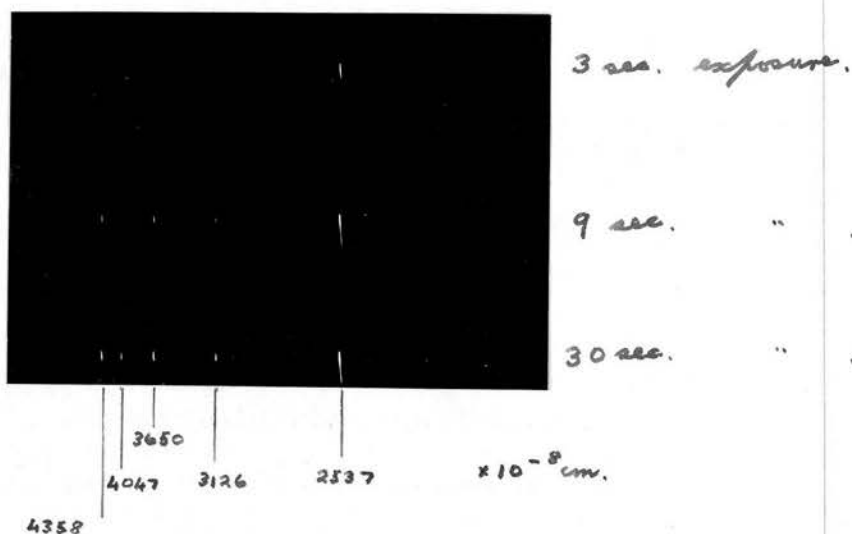
Fig. 6.

Light Output as a Function of Current and Pressure.



-Plate 1.-

The absorption of ultraviolet light by Transpex.



-Plate 2.-

Spectra of light emitted by a lamp filled with argon to a pressure of 6mm. Hg. and containing mercury vapour.

the pressure of argon present.

It was necessary to discover how the efficiency of the lamp varied, defining efficiency as the percentage of 2537 A light in the total light emitted by the lamp and measured in terms of photocell output. The spectra in Plate 1 were obtained by focussing the light from a high pressure mercury vapour lamp on the slit of a quartz spectrograph. In several cases a piece of Transpex $\frac{3}{32}$ inches thick was inserted in the path of the light. This had the effect of completely eliminating all wavelengths lower than 2967 A while leaving the rest of the spectrum unaffected. Since the 2537 A line is by far the most intense emitted by the low pressure lamp, it was decided that little error would occur if the results of intensity measurements for light from this source passing through Transpex, were interpreted on the assumption that this filtered out the light of wavelength 2537 A and nothing else.

On this basis figures for lamp efficiency were obtained which are plotted in Fig. 7 and which show only a slow rise in efficiency with increase of pressure. It is also seen that the efficiency of the lamp falls off with increasing current. Since higher pressures require higher H.T. voltages to 'strike' the lamp, it seemed that a tube filled with argon at

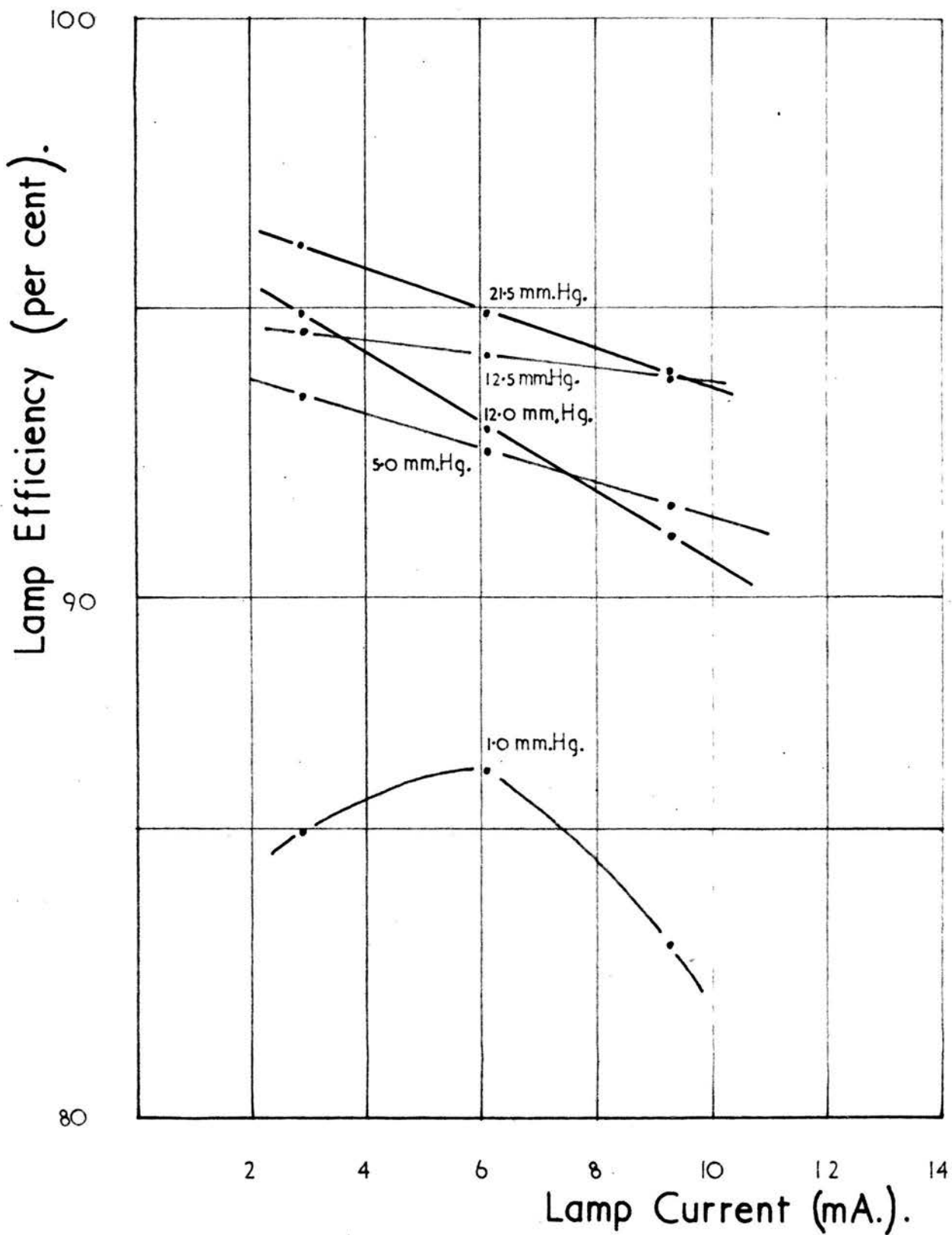


Fig. 7.

Lamp Efficiency as a Function of Current and Pressure.

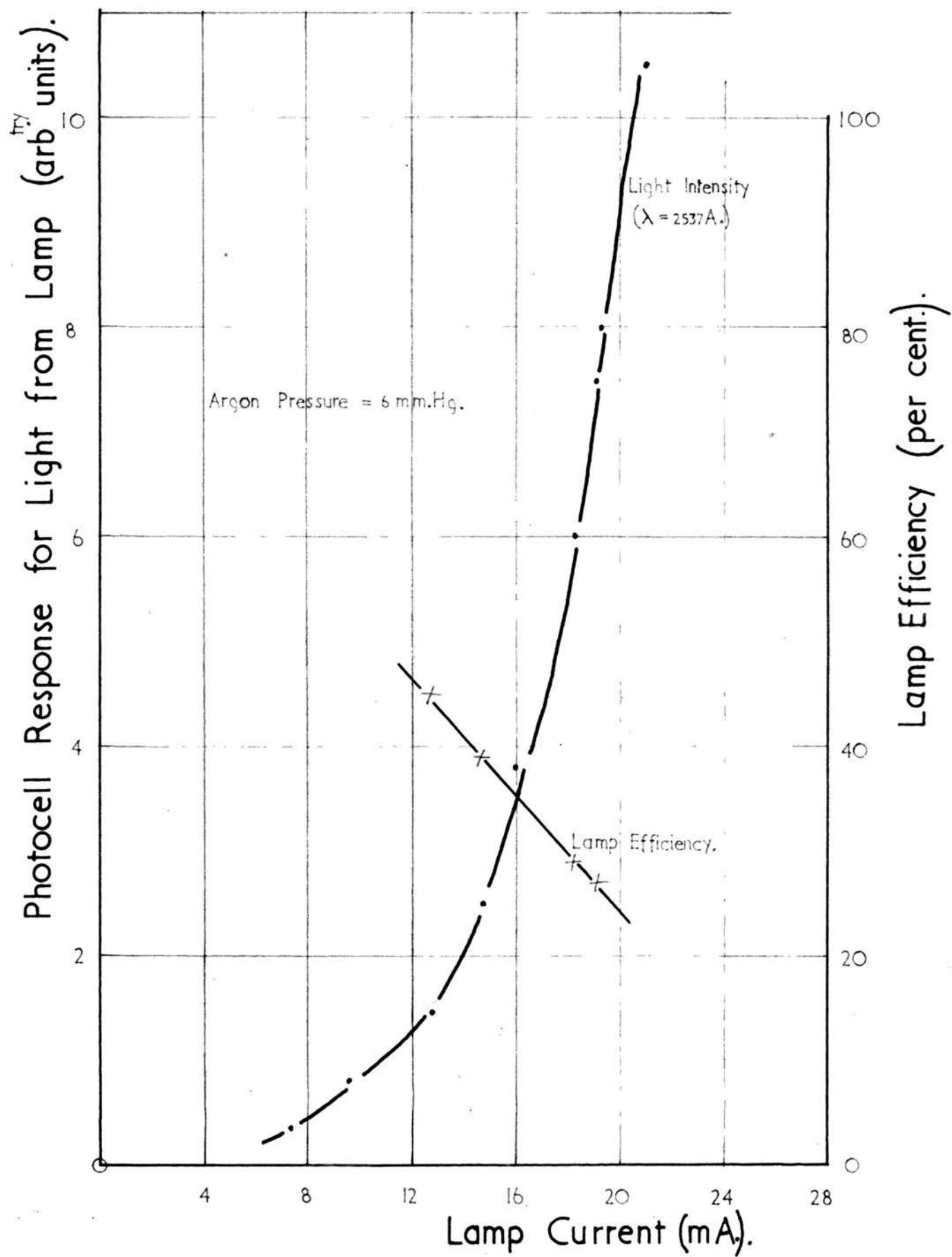


Fig. 8.

Light output and Lamp Efficiency for High Currents.

a pressure of 6 mm. Hg. and run at a current of 8 m A was suitable, the efficiency of such a lamp being about 92%. The spectrum of light emitted by a lamp under these conditions is shown in Plate 2.

It was found, however, that the intensity of the 2537 A light emitted by this lamp was not sufficient for the requirements of the instrument. Fig. 8 shows the relation between the intensity of the 2537 A light from the lamp and the efficiency of the lamp for higher tube currents. For these readings the photocell was connected to its amplifier and the lamp was pulsed, this giving actual working conditions. The amplifier output could be regarded as directly proportional to the photocell current and the current through the tube was measured by the voltage it produced across a 1000 ohm resistor in series with the lamp. The graph shows that greater intensities of 2537 A light can be produced at the expense of lamp efficiency which becomes very poor when the lamp is flashed by sharp pulses of high current density.

These last results made obligatory the use of a filter in front of the photocell to cut down the unwanted radiations. If the efficiency of the lamp-photocell unit were not artificially improved in this way, the amplifier would be hopelessly overloaded.

A temporary filter was made and, with it in

in front of the photocell, the output of the amplifier was noted as the pressure of the argon inside the tube was increased. In this case the optical arrangements were identical with those to be used in a flight, i.e. a reflector behind the lamp and the nine mirrors at a distance of five metres to give a ten metre absorption path between lamp and photocell. The results are plotted in Fig. 9.

No improvement in performance was found when neon was used instead of the argon or when different mixtures of the two gases were tried. From a study of Fig. 9 it was decided to fill the lamp with argon at a pressure of 16 mm. Hg. The required current density was produced by discharging a .5 mF. condenser through the lamp in series with a 220 ohm resistor, the H.T. voltage being 200 volts.

The pressure of mercury vapour in the lamp is the saturation vapour pressure of mercury at the temperature of the lamp (0.001 mm. Hg. at 20°C). The effect on the light output of the lamp when the mercury reservoir was gently warmed with a flame was investigated by observing the output of the photocell amplifier on a C.R.O. No significant change in amplitude was found.

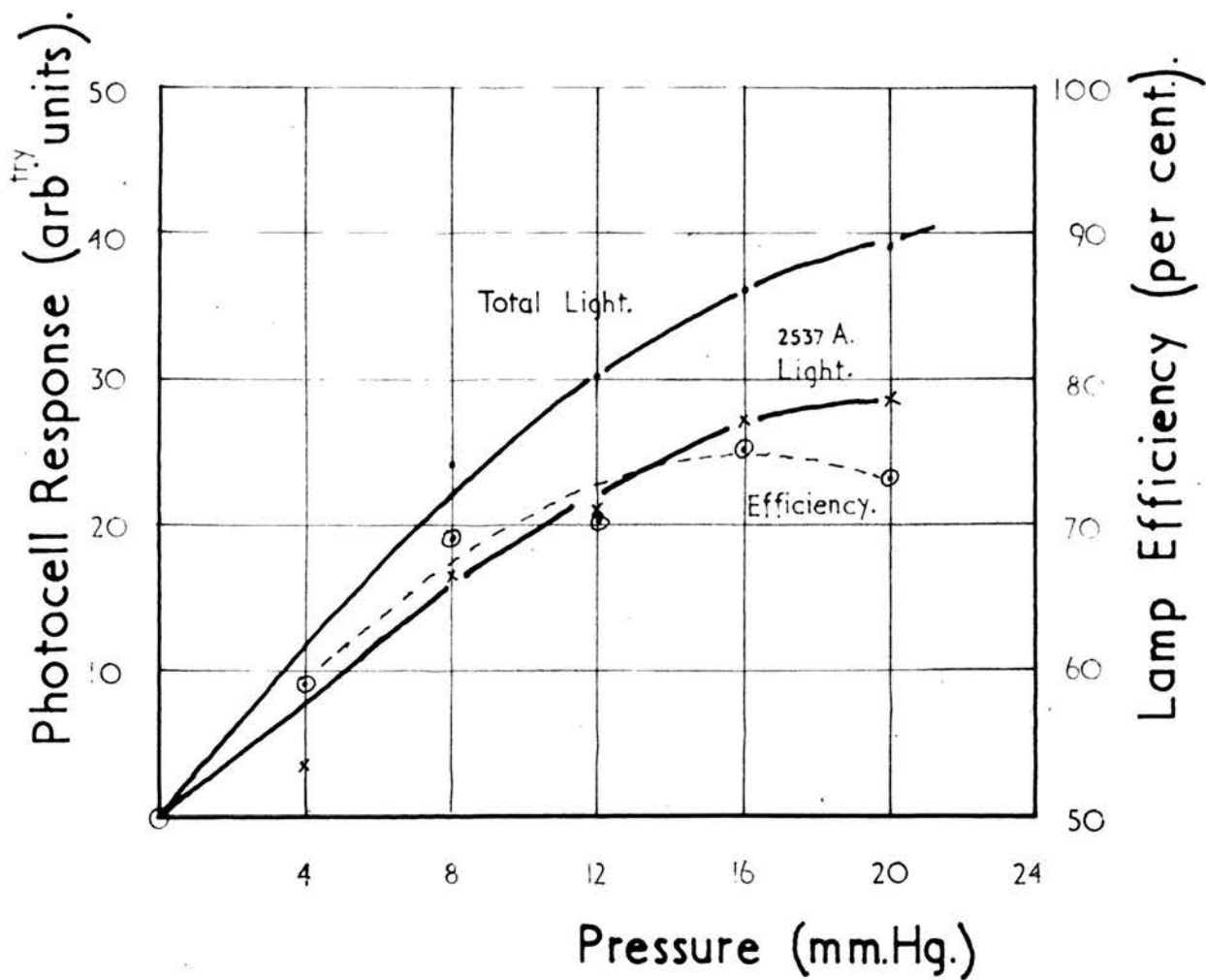


Fig. 9.

Characteristics of Lamp-Filter-Photocell Link.

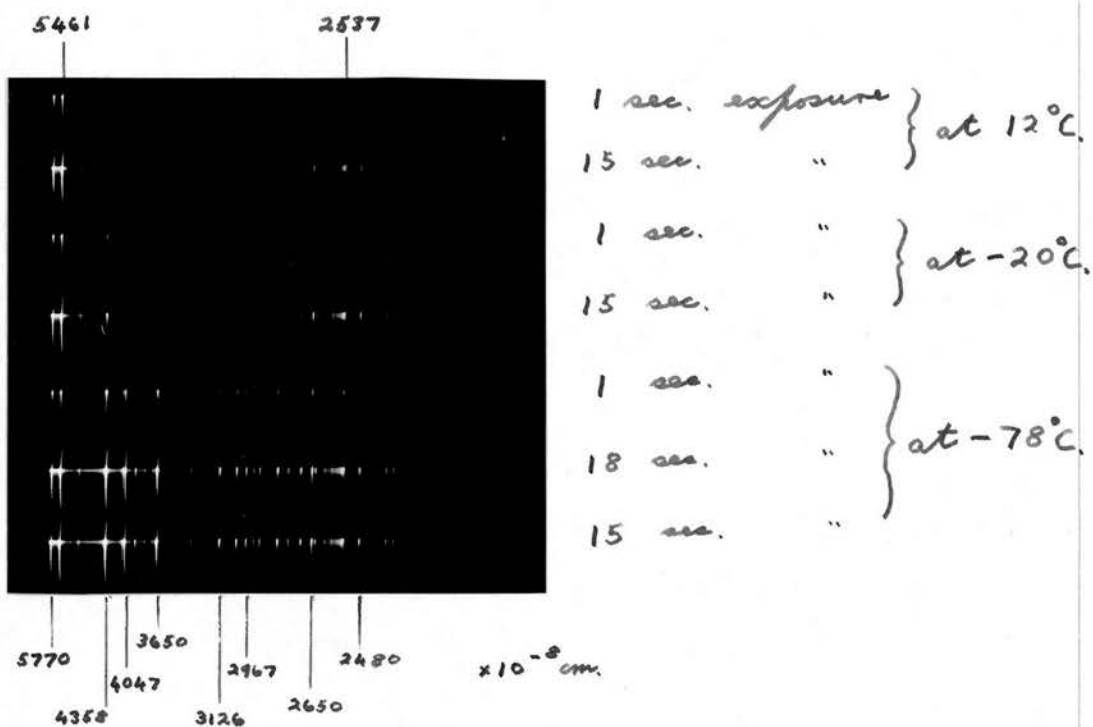
(a) The Optical Parts - (ii) the light filter.

There are four main types of filter which can be used to transmit ultraviolet light while absorbing visible light:-

- I Thin films of the alkali metals.
- II Filters containing chlorine and bromine.
- III Filters containing aqueous solutions of inorganic salts.
- IV Commercially-made glasses.

I. A thin film of potassium will reduce visible light by a factor of 500,000 while only reducing the intensity of wavelengths below 3000 Å by a factor of 4. R.W. Wood (1933) studied these films of alkali metals but his films were not permanent at room temperature. H.M. O'Bryan (1935) produced a quartz-enclosed film which was permanent even at 100°C but the useful width of the filter was very small. It would have required much research and very specialised techniques to adapt this type of filter to the requirements.

II. The properties of the second type of filter were studied and Plate 3 shows the nature of the results obtained. The spectra shown were produced by light from a high pressure mercury vapour lamp passing through the filter and focussing on the slit of



-Plate 3.-

Mercury spectra through a filter containing chlorine and bromine.

a quartz spectrograph. The filter was a sealed quartz bulb containing the chlorine and liquid bromine at just under atmospheric pressure. Similar exposures were given for three different temperatures of the filter and the resultant spectra showed the individual effects of each of the two substances. According to the table below, while both are active at 12°C , only chlorine is effective at -20°C and neither vapour is present in any quantity at -78°C .

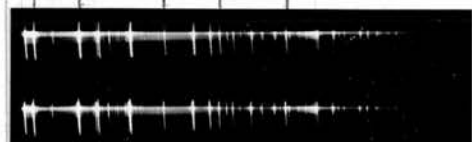
Element	Pressure of Vapour in Filter		
	at 12°C	at -20°C	at -78°C
Bromine (M.P. -7.3°C)	101.5 mm Hg.	13.1 mm Hg.	.0025 mm Hg.
Chlorine (B.P. -34°C)	760 "	760 "	64.4 "

At 12°C the filter is cutting out a region from 4358 A to 2650 A while transmitting the yellow and green lines and, to a lesser extent, the 2537 A line.

With much of the effect of the bromine removed at -20°C , it is seen that the lines between 4358 A and 5461 A are now getting through while the transmission of the other wavelengths has improved generally.

At -78°C the chlorine also is not sufficiently

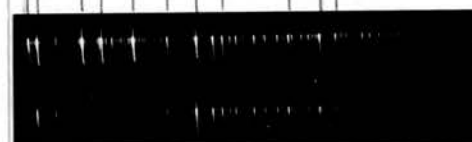
5461 4358 3342 2967 2650



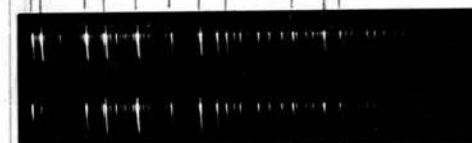
5 sec. exposure, filter out. } Distilled water.
in. }



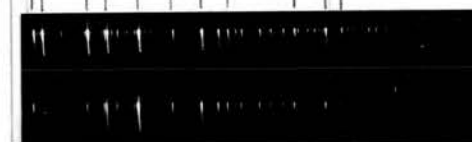
5 sec. out. } 100 gm./l. NiSO₄.
in. }



5 sec. out. } 500 gm./l. NiSO₄.
in. }



3 sec. out. } 50 gm./l. CoSO₄.
in. }



3 sec. out. } 100 gm./l. CoSO₄.
in. }



1 sec. in. } 100 gm./l. NiSO₄
out. } +
50 gm./l. CoSO₄.



1 sec. out. } 150 gm./l. NiSO₄
in. } +
45 gm./l. CoSO₄.



1 sec. out. } 240 gm./l. NiSO₄
in. } +
45 gm./l. CoSO₄.



30 sec. in. }

4047 3650 2577 3126 2480 5770

$\times 10^{-8}$ cm.

-Plate 4. -

Mercury spectra through filters containing NiSO₄ and CoSO₄ solutions.

dense to produce much absorption and there is almost a complete mercury spectrum, only a small band between 3126 A. and 3650 A. being absent.

While this filter is satisfactory in the near ultraviolet, it does not absorb visible light sufficiently strongly for our purpose.

III. The absorbing properties of aqueous solutions of nickel and cobalt sulphates, contained in an absorption cell 5 cm. long, were investigated with the high-pressure lamp and quartz spectrograph. Various spectra obtained are shown in Plate 4.

The nickel sulphate is very effective in cutting down the region 3342 A. to 4358 A. and, roughly speaking, absorbs everything above 3126 A. with the exception of the 5461 A. (green) line.

The cobalt sulphate cuts out visible light between 4358 A. (blue) and 5770 A. (yellow) and also has an absorption band in the ultraviolet which weakens the 2537 A. line slightly and shorter wavelengths to an increasing extent.

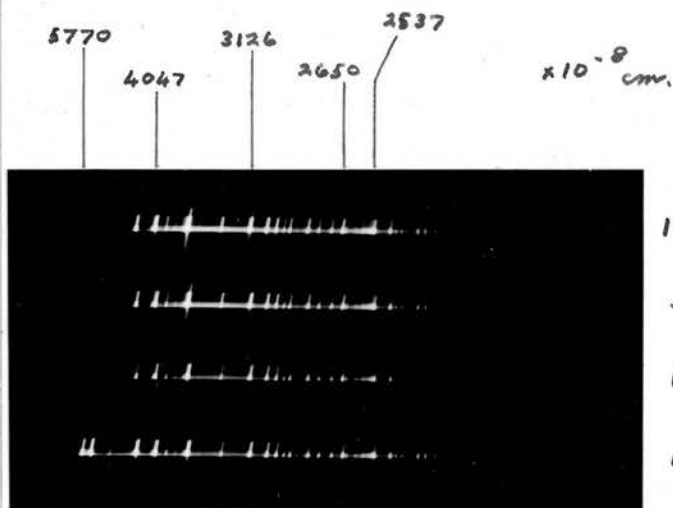
The effects of three different mixtures of the salts are also shown, the first passing a fair amount of visible, as well as ultraviolet, light and the second transmitting a band from 2480 A. to 3342 A. with just a trace of the 5770 A. (yellow) line. The third and most concentrated solution lets through

light in the range 2537 A. to 3126 A. Other lines visible on the original plate are 2480 A., 3342 A. and faint traces of the green and yellow lines.

In a survey of transmission filters for the ultraviolet, Kasha (1948) gives the following figures. A 5 cm. path of aqueous solution containing 240 gm./litre nickel sulphate and 45 gm./litre cobalt sulphate (i.e. as in the last case described), transmits about 50% of the incident light in the region 2400 A. to 3200 A. and no other light except for a few per cent of the incident 5700 A. light.

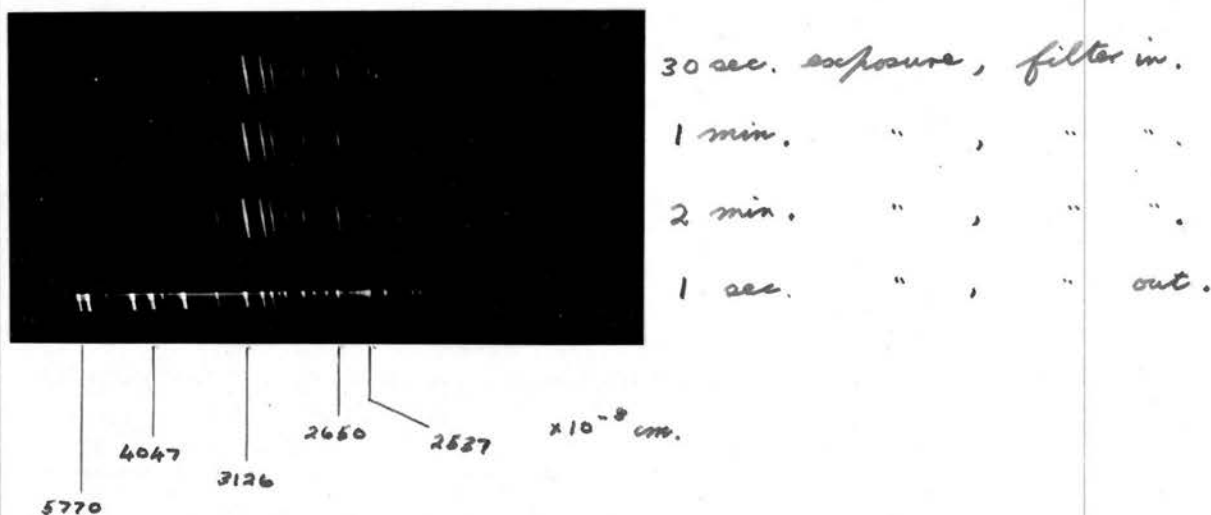
The final filter adopted consisted of this last concentration of nickel and cobalt sulphates in water with the addition of an item from group IV -- a piece of the OX7 type of phosphate glass manufactured by Chance Bros. Ltd. Plate 5 shows the high pressure mercury spectrum, first through a 2 mm. thickness of OX7 glass alone, and then through the complete filter. It is seen that the OX7 improves the absorption properties in the visible and near ultraviolet while leaving the 2537 A. transmission virtually unchanged.

The construction of the filter can be seen in Plate 6. The dark green solution of the two salts is contained in a glass tube 5 cm. long and about 4 4 cm. in diameter. Quartz discs are cemented on to



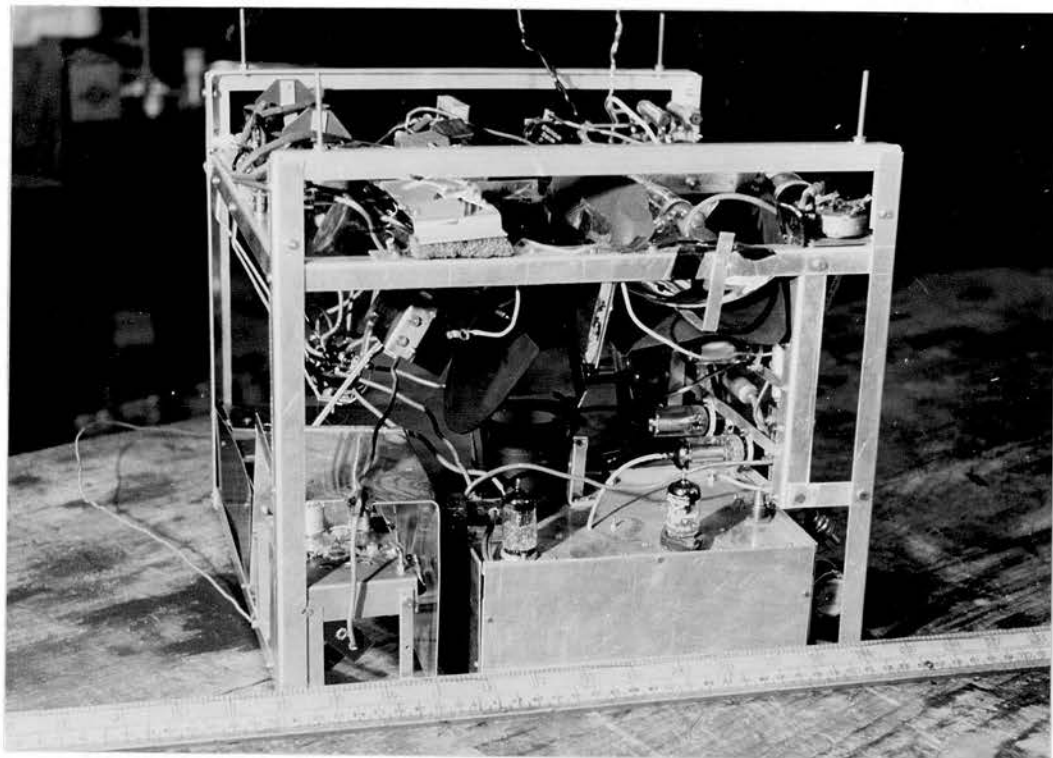
-Plate 5a.-

Mercury spectra through OX7 glass.



-Plate 5b.-

Mercury spectra through the complete filter which consists of 5cm. of salt solution plus a 2mm. thickness of OX7 glass.



-Plate 6, -

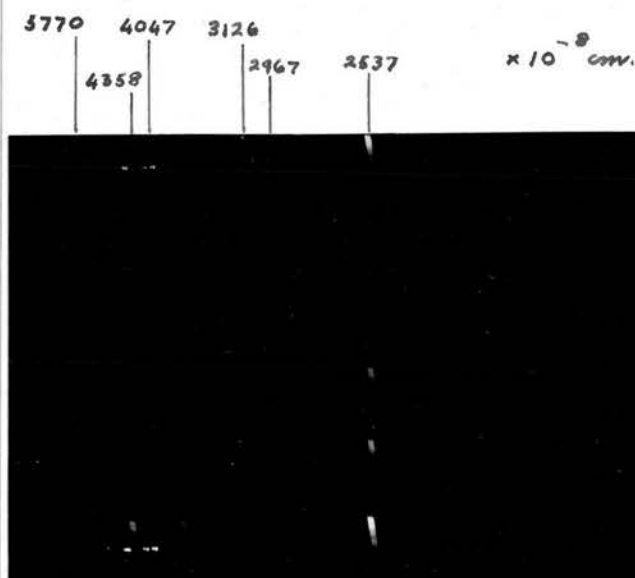
Radio sonde showing the filter mounted on the photo-cell amplifier. The rotating sector can also be seen.

each end of the tube and the OX7 glass, deep violet in colour, is clipped on to the surface of the upper disc. The sides of the filter are painted matt black to cut down stray light. When this filter is directed at a bright electric light bulb only a very faint blue light can be observed.

The cell is filled through a small glass tube which comes out from the side of the main tube and bends upwards. When filling is completed so that the level of liquid in this tube is higher than the top of the cell, this side tube is sealed up to prevent contamination of the solution and evaporation of the water solvent. Before an ascent, a tiny hole is made in the top of the side tube to allow the air inside to escape.

While the cell described above is called the filter, there are two other items which also act as filters and must be considered when attempting to determine the relative intensities of the wavelengths emitted by the lamp and received by the photocell.

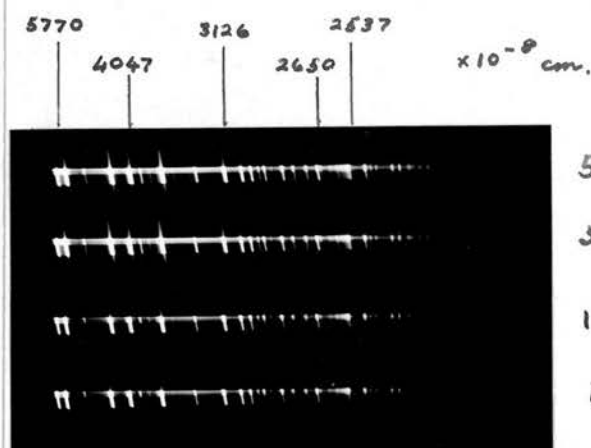
Firstly the drop in reflectivity of the aluminium mirrors in the ultraviolet part of the spectrum adversely affects the proportion of 2537 A. light in the total light reaching the photocell. To obtain the spectra recorded in Plate 7, the low-pressure source was pulsed and the light was reflected from an



100 light pulses from lamp, filter out
 100 " " " " " "
 200 " " " " " "
 500 " " " " " "
 1,000 " " " " " "
 200 " " " " " "

-Plate 7.-

Spectra of the light emitted by the low-pressure source, reflected from an aluminium mirror and transmitted through the filter.



5 sec. exposure, filter out.
 5 sec. " " " in.
 1 sec. " " " out.
 1 sec. " " " in.

-Plate 8.-

Mercury spectra through OW1 glass.

aluminised Perspex mirror on to the slit of the spectrograph in front of which the filter could be placed. Only three lines are visible on the original plate for the path with the filter included -- those of 2537 A., 3126 A. and 2967 A. in order of intensity, the last named being very faint indeed. Tests with Transpex which absorbs some of the 2967 A. light and all of the 2537 A. light, gave the fraction of 2537 A. light to total light, as measured by the photocell, as 94%.

In the second place, account has to be taken of the effect of the windows in the container of the instrument. The light traversing the absorption path has to pass through these windows on both its outward and inward journeys. Layers of pure cellulose as thin as .0008 inches were tried but caused too much absorption and the windows had to be made of OW1 glass supplied by Chance Bros. Ltd. Plate 8 shows that there is very little absorption when the OW1 (2 mm. thick) is interposed between the high-pressure arc and the spectrograph.

When the more sensitive Transpex test was made, however, it was found that the percentage of 2537 A. light had fallen to 83%. This referred to light from the low-pressure source emitting from a double window, traversing a ten metre path including a reflection at

an aluminium surface, and re-entering the container through a second double window before passing through the filter and finally reaching the photocell. The remaining 17% of the light was almost entirely of wavelength 3126 A.

The absorption coefficients of ozone for the wavelengths 2537 A. and 3126 A. are around 140 and 1 respectively. In practice this means that, if the output of the photocell amplifier is 30 volts, then 5 volts of this will not be affected by changes in ozone concentration, and so the variation will take place in 25 volts in the presence of an additional constant factor of 5 volts.

(a) The Optical Parts - (iii) the mirrors.

It has already been mentioned that to obtain a ten metre absorption path, the light from the lamp had to be collimated to some extent by having a cylindrical reflector behind the quartz lamp, and by having the mirror compounded of nine small mirrors orientated to produce a focussing effect. These items, together with the rotating sector, are all made of Perspex and given a thin, highly-reflecting coating of aluminium in the laboratory.

The nine mirrors are each $2\frac{1}{2}$ inches square and $\frac{1}{8}$ inches thick; the rotating sector is semi-circular in shape with radius $2\frac{1}{4}$ inches and thickness

$\frac{1}{16}$ inches; the reflector is bent into an arc of 120° with radius 3 inches out of a 6 inch length of sheeting 3 inches wide and $\frac{1}{16}$ inches thick. This bending is done by first making the Perspex pliable by dipping it in boiling water, after which it is clamped to a brass template of suitable curvature and left in the boiling water for about 30 minutes.

It was found to be impossible to polish the Perspex without leaving very fine scratches which completely ruined the reflecting properties and so the surface prepared by the manufacturers is left unaltered and is treated with great care in the cleaning processes which have to be undertaken before the aluminium can be deposited.

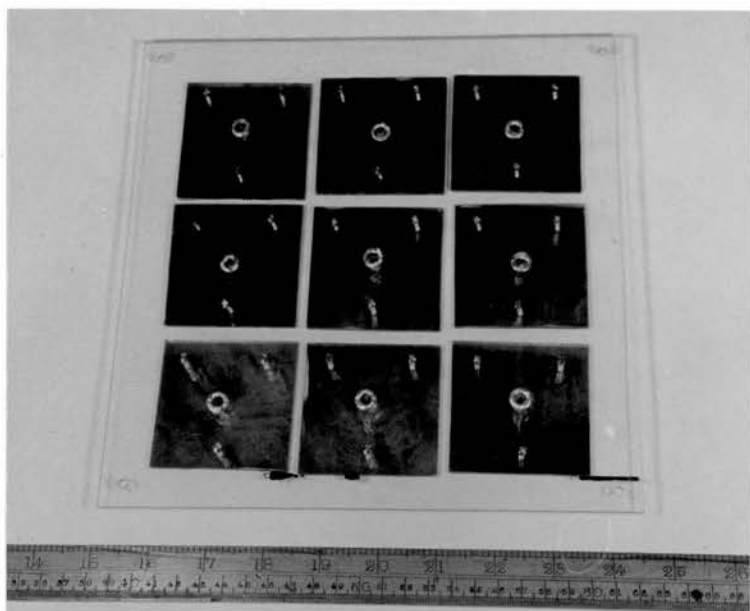
To make a good mirror, the Perspex surface has to be absolutely clean and hydrogen peroxide is an efficient substitute for the usual chromic acid cleaning agent which cannot be used in this instance. After cleaning, the Perspex is given a series of washings in distilled water and is dried in a current of clean, warm air. It is then ready to have its coating of aluminium.

This is done in an apparatus consisting of a bell-jar on a brass support in which are set three insulated terminals. Between two of these terminals is placed a tungsten filament made up of three 0.5 mm.

diameter wires bound together by a length of wire of 0.2 mm. diameter. A small section in the middle of the filament is bent into a V-shape and this is made to grip a piece of aluminium wire about $\frac{3}{4}$ inches long and $\frac{1}{16}$ inches in diameter. The air inside the bell-jar is pumped out, the pressure being indicated by the nature of the discharge produced when a high voltage is put on the third terminal. The evacuation is continued until the discharge 'blacks out' indicating a pressure lower than 10^{-4} mm. Hg. A current of about 30 amps. is then passed through the filament causing the aluminium to melt and run along the tungsten wire which is then heated still more strongly causing the aluminium to be thrown off. The Perspex surfaces, placed sufficiently far from the filament to be unaffected by the heat, then receive a thin uniform layer of aluminium.

Trouble was experienced in the mounting of the nine mirrors. Each had to be capable of easy adjustment and had to be rigid enough to prevent disarrangement through unavoidable shaking. Most devices which were tried to hold the mirrors firmly, applied stresses to the mirrors which then underwent gradual plastic deformation. The final arrangement used is shown in Plate 9.

The flat Perspex supporting plate, $\frac{1}{2}$ inches thick,



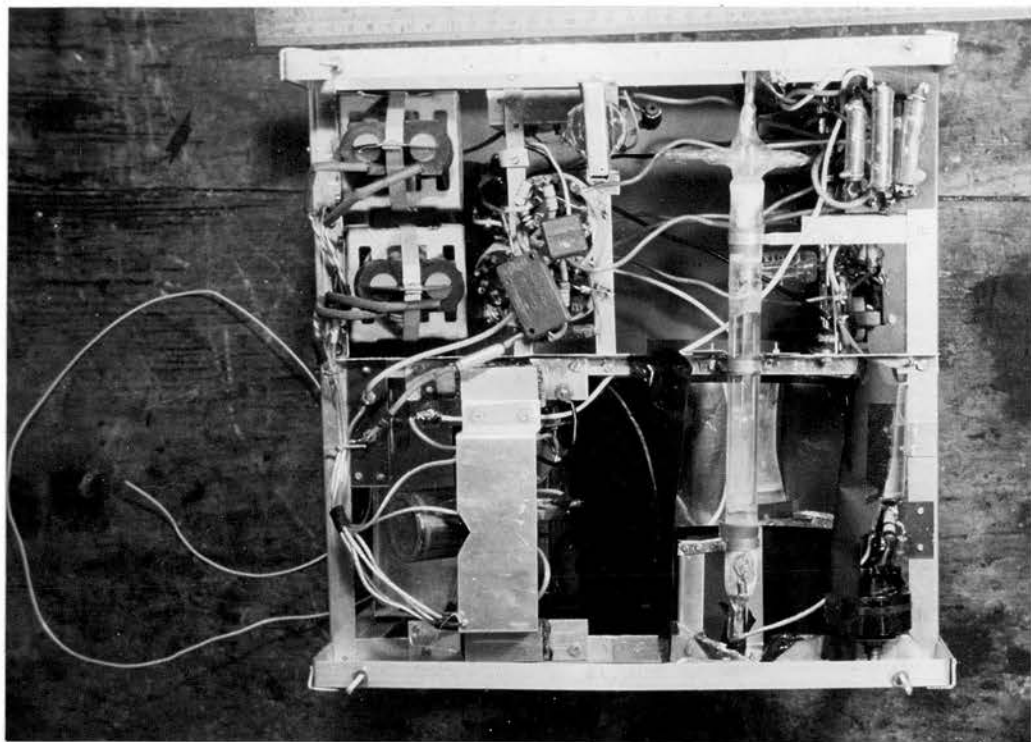
-Plate 9. -

The nine mirrors seen from the back through
their Perspex supporting plate.

is 9½ inches square and contains nine suitably placed holes through which pass small steel springs fixed to the backs of the mirrors. The ends of these springs are held to the plate by soldering them to nine brass washers. Each mirror can then be adjusted by means of three screws threaded through the supporting plate and pushing against the back of the mirror. By making the mirrors out of Perspex, ½ inches thick, and by keeping the tensions in the springs low, the mirrors are not deformed and still retain a certain amount of rigidity.

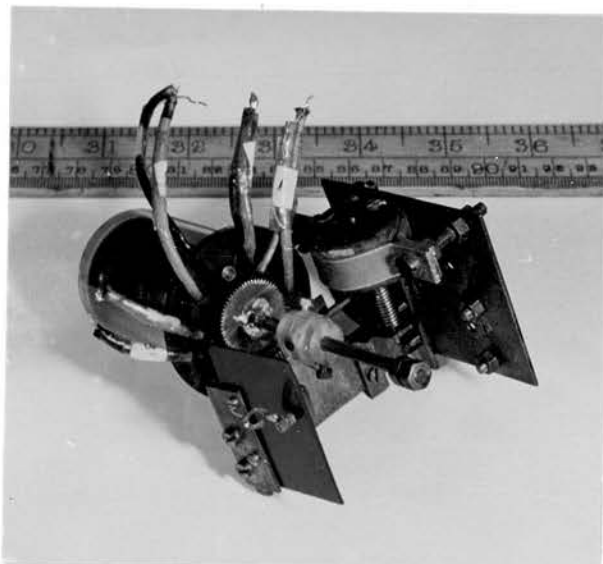
The back of the rotating sector is painted matt black and this ensures that, in one position, the sector reflects light from the lamp straight into the photocell while cutting out the long path completely. In the other position of the sector, only light from the long path can reach the photocell. A simple slit arrangement is used to keep the light intensity from the short path of the same order as that from the long path. The sector can be seen in Plates 6 and 10 which also show how the lamp is shielded to prevent unwanted light reaching the photocell.

Plate 11 shows the driving mechanism for the sector. A small electric motor, an Electrotor Model 240, is made to drive a spindle through two 60 : 1 reduction gears. Although designed for operation by



-Plate 10. -

Top view of the radio sender showing the lamp and its reflector, the sector and (top left) the pressure and temperature elements.



-Plate 11. -

The motor and driving mechanism for the
rotating sector and the switches.

a 4.5 volt battery, this motor can be run off 2.4 volts and gives about 3,500 r.p.m. with a current drain of around 150 mA. The spindle on which the sector is mounted thus makes roughly one revolution in a minute.

Since measurements of light intensity would be misleading during the transitional periods between the two paths, a mechanism is fitted on the spindle and ensures that no such measurements are made during these times. The principle of the switch is that, during the change-over periods, a wire brush pressing on an insulated collar fixed to the rotating spindle, encounters earthed metal studs set in the collar. This short-circuits part of the telemetering system described later, causing the temporary cessation of intensity measurements.

The arrangement in the celluloid cover which can be seen in Plate 11 is another type of switch gear driven off the same little motor. During a flight, measurements of temperature and pressure have to be transmitted to the ground and this switch is used to connect the temperature element and the pressure element alternately into the telemetering circuit. The type of switch used by the Meteorological Office in their radio sondes is employed with a few modifications.

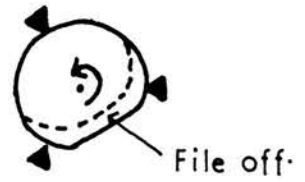
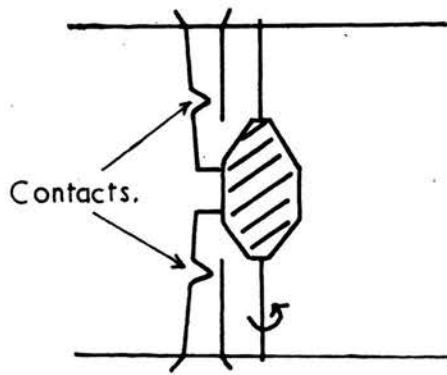


Fig. 10.

Principle of the Meteorological Switch.

Firstly, instead of being actuated by a wind-vane, the switch is, of course, motor-driven. Secondly, a normal radio sonde has three elements -- pressure, temperature and humidity -- whereas the ozone apparatus only uses two, the humidity element being omitted. For this reason two of the three sets of contacts are paralleled-off and used for the pressure element. Finally, in the ordinary radio sonde it does not matter if one set of contacts opens before the next set closes but this is undesirable in the ozone radio sonde in view of certain features of the telemetering system. The switch is therefore treated to prevent this occurrence. Figure 10 shows how the gold-plated phosphor-bronze contacts are forced apart and then allowed to spring together by the rotation of an insulated cam. By filing off a part of this cam, as shown by the dotted line, it is arranged that one set of contacts closes before the previous set has opened.

As far as is possible the change from the pressure to the temperature element is made to synchronise with the change from the long to the short path and vice versa. This gives a means of distinguishing the paths, one from the other, if ever there is any doubt.

(a) The Optical Parts - (iv) the arrangement of the absorption path.

It would have been advantageous to use multiple reflections from several sets of mirrors to obtain the ten metre absorption path, since then the physical size of the path could have been made small. The light output of the lamp and the loss entailed at each reflection, however, combined to render this arrangement impracticable. Equally impossible was the construction of a rigid framework five metres long to hold the mirrors in a fixed position relative to the lamp and photocell. To have been at all effective a framework of prohibitive weight would have been required. Thus the problem was to find some way, involving as little weight as possible, whereby the nine mirrors could be supported five metres from the lamp, in such a manner that they would remain fixed relative to the lamp and would reflect its light back to hit a target less than 1½ inches square, irrespective of how the whole apparatus was swinging or twisting.

The system whereby three mirrors, mutually at right angles to each other, reflect light back along its incident path, was unsuitable since it involves three reflections with a subsequent loss of light intensity. A surprisingly stable arrangement was found

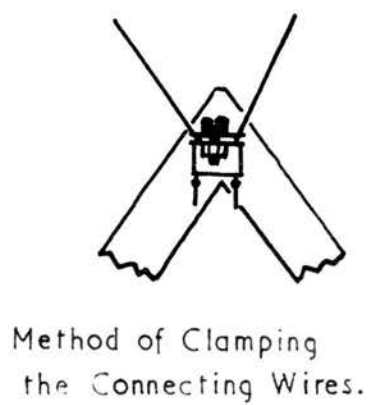
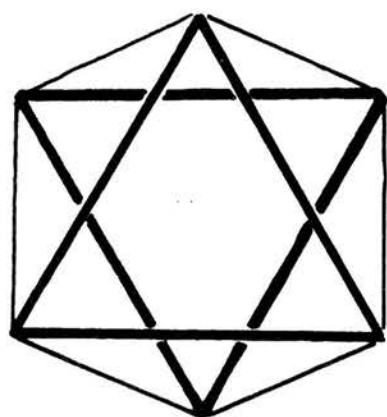
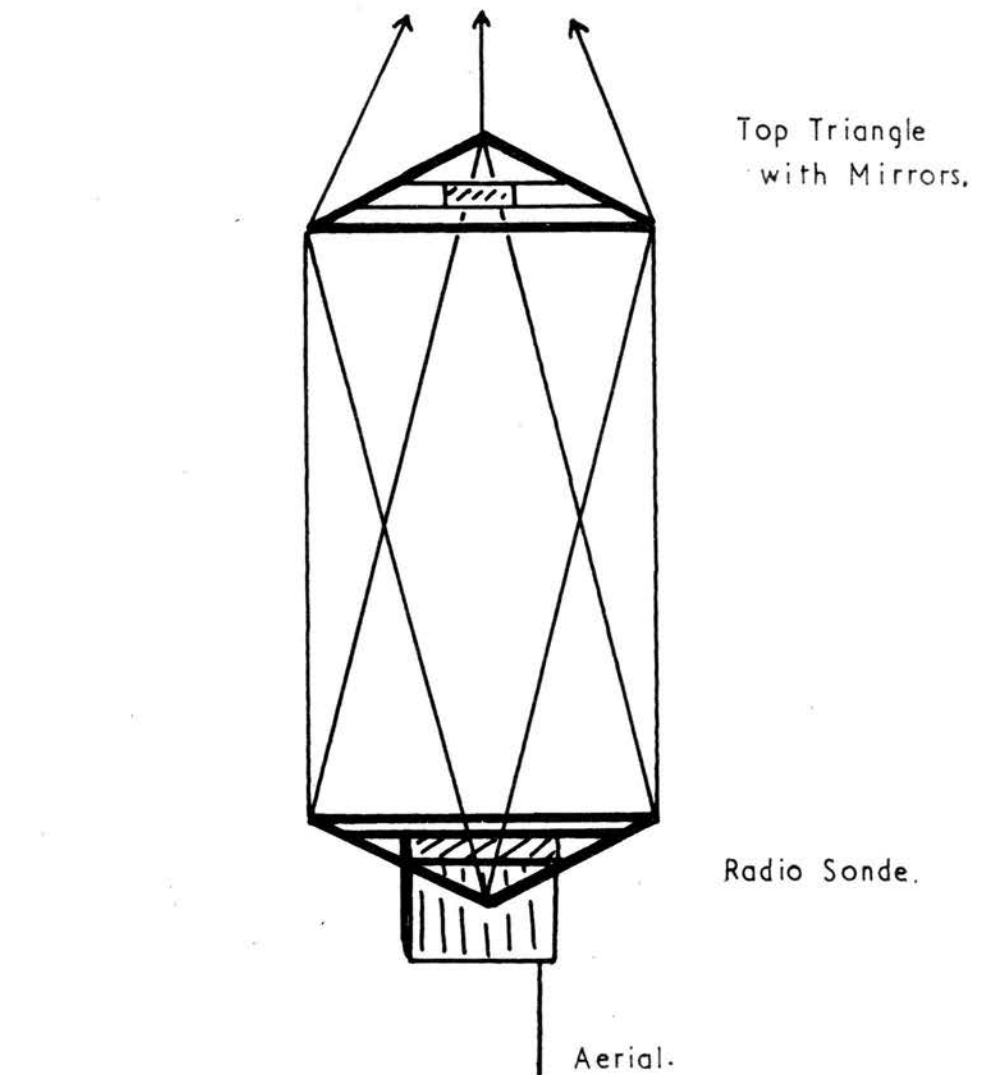


Fig. II.
Arrangement of the Absorption Path.

to be produced when two triangular frameworks were connected by wires as shown in Figure 11.

The triangles, of one metre side, are entirely constructed of $\frac{1}{16}$ inch thick aluminium sheet bent into $\frac{3}{4}$ inch angled strips. The upper triangle is fitted to hold the nine plane mirrors on their Perspex support and the lower to carry the radio sonde in its container. The connecting wires are tightly gripped at the corners of the triangles by simple brass clamps which facilitate the adjustment of the tensions in the wires to make the triangles lie in parallel horizontal planes, orientated with respect to one another in the manner shown in the sketch.

The efficiency of this arrangement was tested by clamping a galvanometer light to the lower triangle and focussing it, via a mirror on the upper triangle, on a small white disc back beside the light. A few kilogramme weights were tied to the lower triangle and the whole apparatus set swinging and twisting. The spot of light remained 'glued' to the white disc except when the motion of one triangle was violently altered, an unlikely event during a flight if the rigging has been carefully designed. Apart from this, the only way in which the spot of light could be made to move relative to the disc, was by plucking one

or more of the suspension wires, thus setting up high frequency vibrations which caused the spot of light to oscillate though with very small amplitude -- about $\frac{1}{8}$ inches. These oscillations, moreover, were never observed to arise by themselves and it was concluded that this rather unlikely-looking arrangement was satisfactory.

It was originally intended to make the triangles of wood and to connect them by nylon monofibre cords which are unaffected by humidity or low temperature. These insulating materials would not have affected the aerial which could then have been suspended between the triangles. However the nylon was found to 'creep' when stressed and, due to its elastic properties, was inferior to wire which had therefore to be used. Multi-stranded steel wire was adopted as being easier to handle than the springier single-stranded variety which was also very liable to kink. The wooden triangles were replaced by aluminium ones with a resultant saving in weight.

(a) The Optical Parts - (v) the photocell and amplifier.

The final item in the absorption-measuring section of the instrument is the part which receives the light

signals and turns them into convenient voltage pulses which are passed on to the telemetering system. The photocell is enclosed in a quartz envelope and is the type QVA 38 made by Cinema-Television Ltd. This is a vacuum type cell which was found to be the most suitable for the purpose. It combines good sensitivity (about $50 \mu\text{A./lumen}$) with instantaneous, linear response to a light pulse, a property vital to the telemetering system. Its output is not critically dependent on applied voltage. These qualities are not inherent in the more sensitive gas-filled cells. The manufacturers merely specify the sensitive material of the cathode to be of 'type A'. There was no possibility of using a sodium surface for the cathode with its response lying mainly in the ultraviolet region of the spectrum since this type of cell has low sensitivity.

The photocell is connected to a straight-forward RC coupled amplifier which has a large resistor in its first grid circuit. Great care has to be taken to avoid stray pick-up at this point. Negative feedback is applied in a conventional manner to the first two stages (Figure 12) in which the valves are EF 95 low-noise R.F. pentodes. The output valve is a DL 92 with which it was found possible to save battery power by

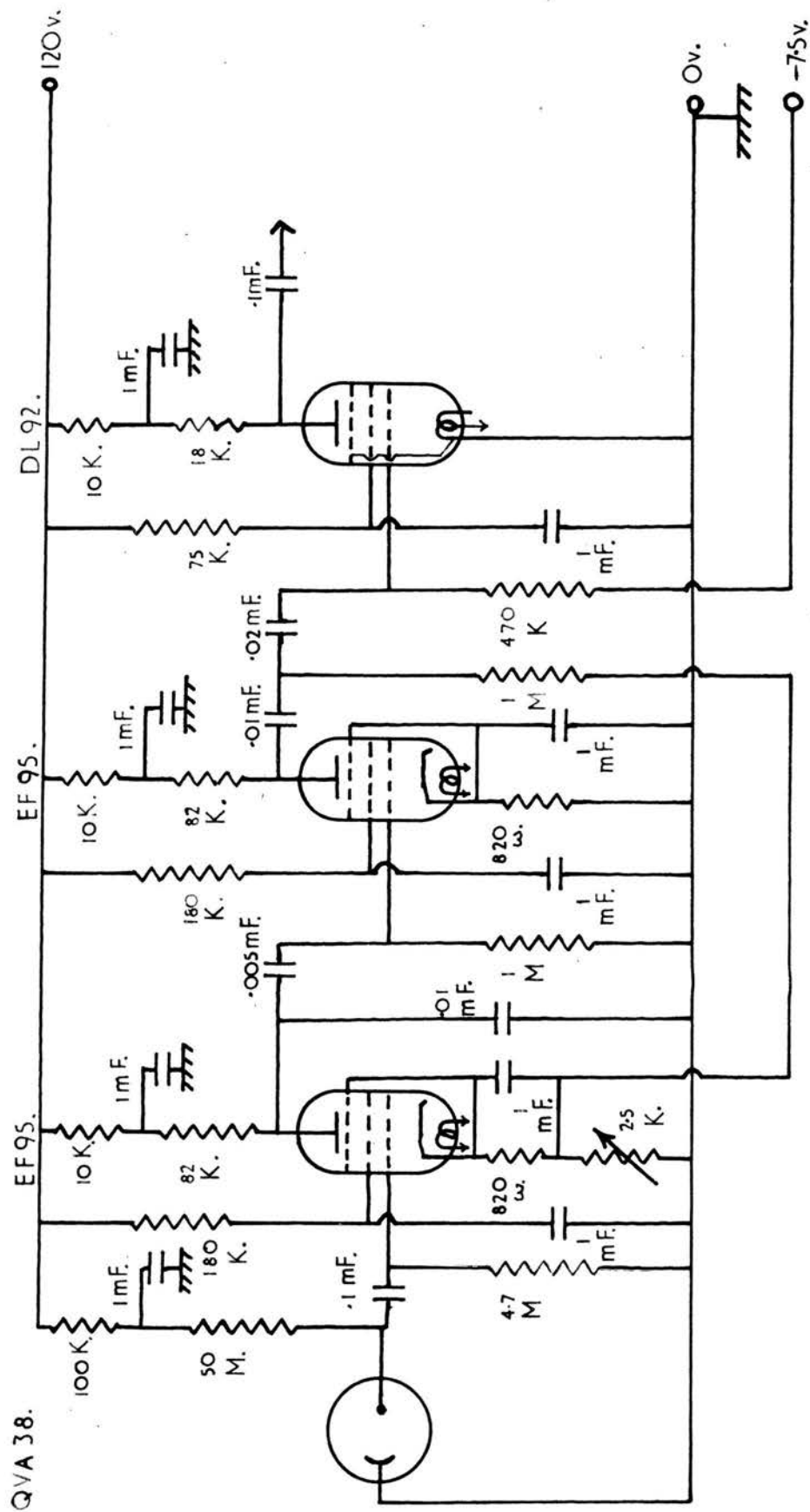


Fig. 12.

Circuit of the Photocell and Amplifier.

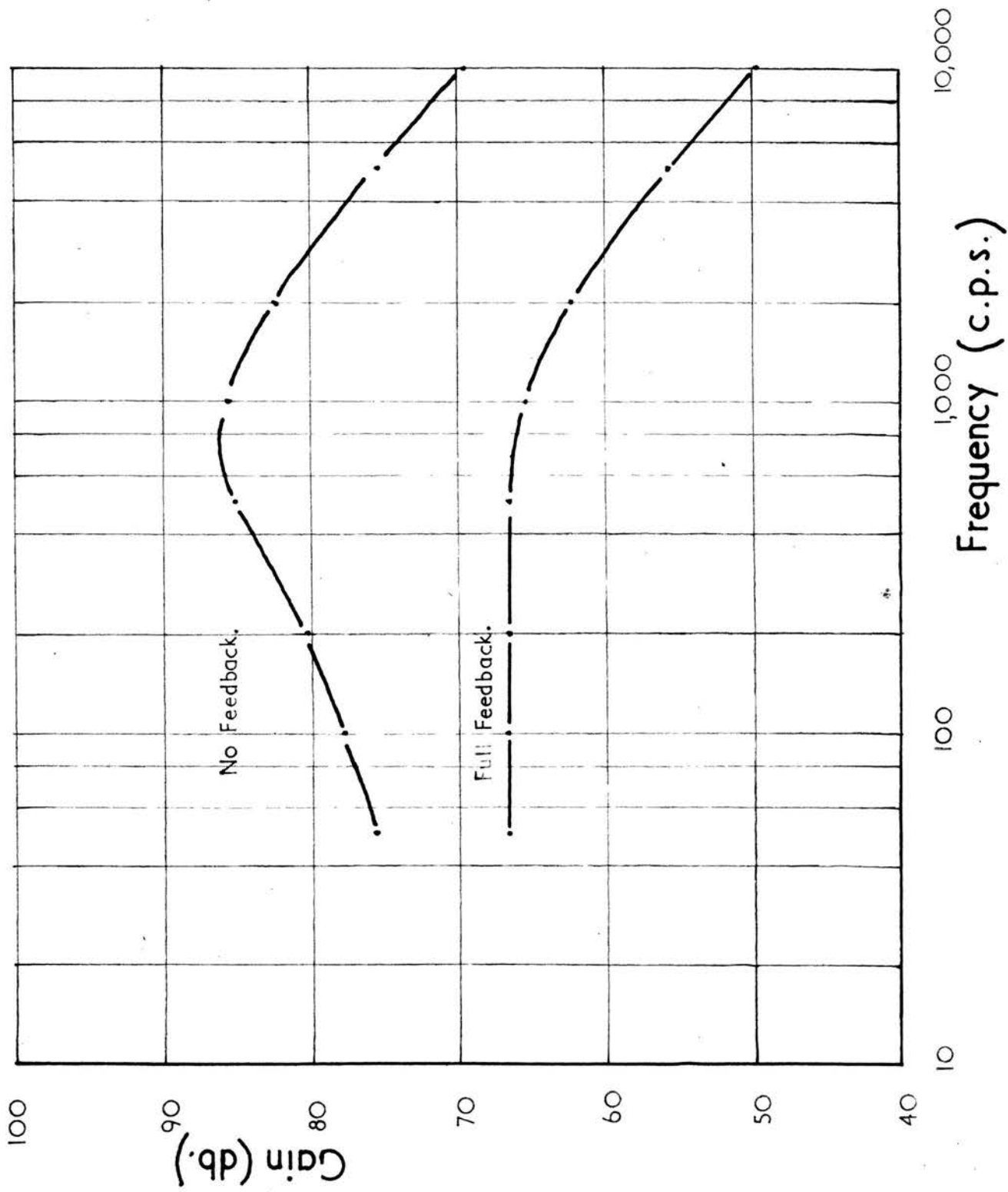


Fig. 13. Amplifier Characteristics.

using only one half of its two-sectional filament. The D.L. 92 is a battery valve and an attempt was made to use similar valves (DF 92^S) for the preceding stages. These directly-heated valves generated too much noise, however, and hence the mains-type valves had to be used with the inconvenience of their heavier power requirements.

The first valve is mounted on a special anti-microphonic base which is visible in the view of the amplifier shown in Plate 6. The photocell and first two stages of the amplifier are mounted on the underside of a shallow aluminium tray, strips of thin aluminium sheeting being used to screen each stage from its neighbours. The valves and the light filter fit on to the top of the tray which forms the lid of an aluminium screening box. A screened connection leads from this box to the output stage which is included with the other battery valves on two strips forming one side of the complete radio sonde.

The performance of the amplifier is shown in Fig. 13. At 1 Kc./sec. the ratio

$$\frac{\text{Maximum gain}}{\text{Minimum gain}} = \frac{19,400}{1,860} = 10.4$$

and the bandwidth is 2.6 Kc./sec. at 6 db. down. The noise levels are 0.6 volts r.m.s. for maximum gain and less than 0.05 volts r.m.s. for minimum gain. These figures agree with the values expected due to thermal noise in the 5 megohm input resistor.

(b) The Telemetering System - (i) the ozone
intelligence.

It has been described above how the intensities of the light passing over the short and long paths are converted to voltage pulses whose amplitudes are linearly related to the intensities. It has also been mentioned that if these amplitudes can be telemetered to the ground with sufficient accuracy during a flight, the vertical distribution of ozone in the atmosphere can be determined. To obtain the necessary accuracy it was decided to transmit the amplitudes of the voltage pulses in terms of time intervals between pairs of pulses.*

This conversion from amplitude to time-delay takes place in what is known as a comparator circuit (Williams and Moody, 1946). The circuit depends, for its initiation, on the lamp flashing (Fig. 14). The rate at which this happens - about twice per second - depends on the time taken by the .5 mF condenser to charge up through the variable resistance until the striking voltage of the lamp is reached, when the condenser discharges very rapidly. This very sharp drop in voltage is used as a gating signal for the

* Thanks are due to Mr. W.E.J. Farvis of the Engineering Department of Edinburgh University for advice on the type of circuitry required.

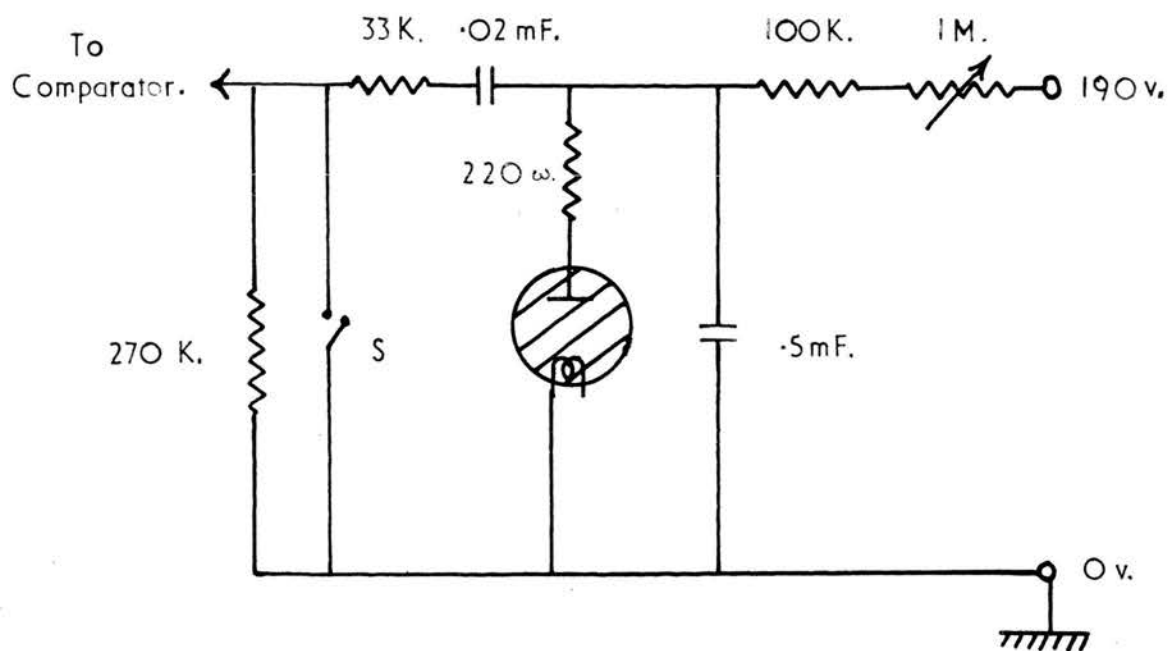


Fig. 14.

Lamp Circuit.

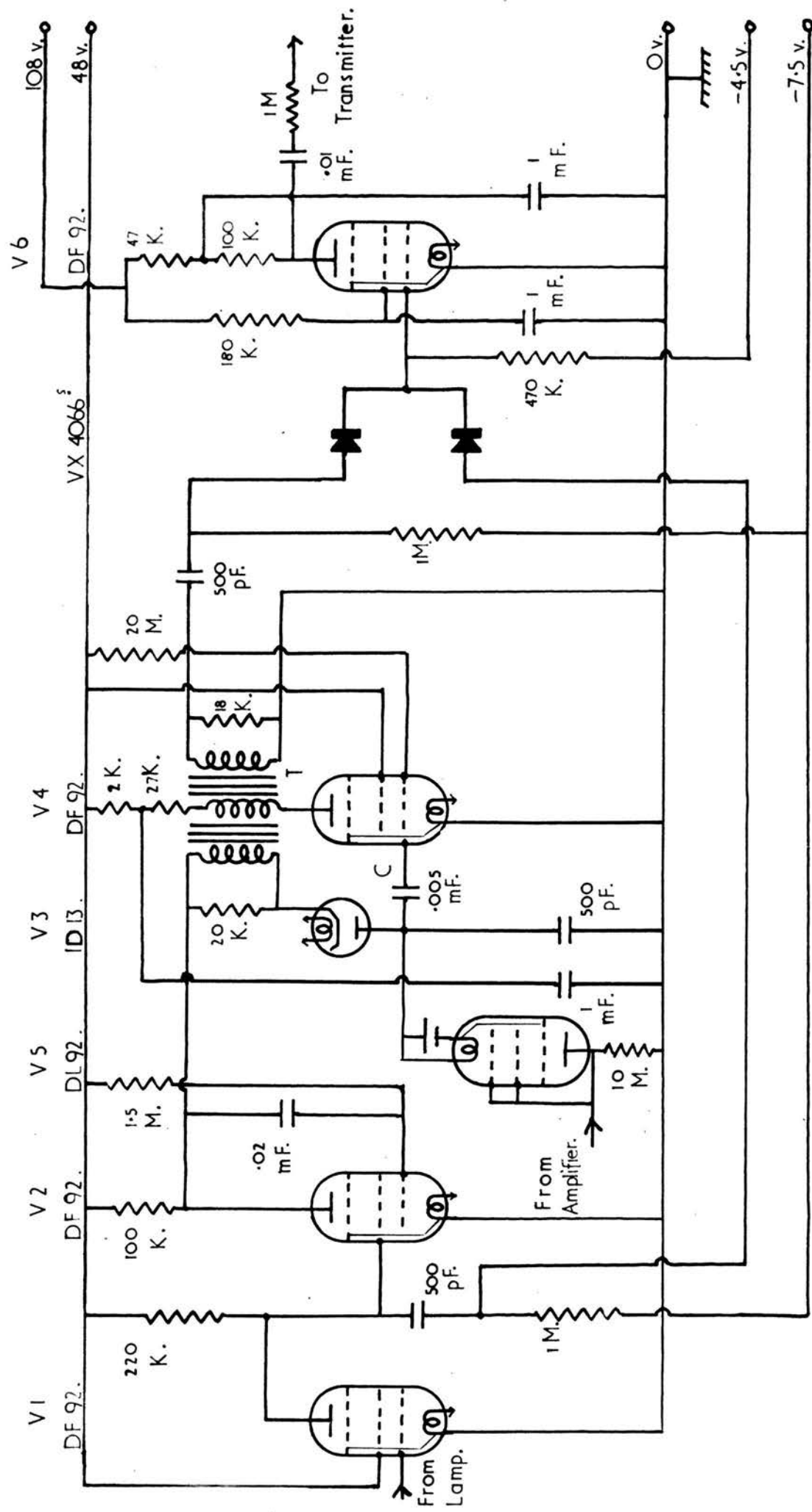


Fig. 15.
Comparator Circuit.

comparator (Fig. 15). It will be noticed that no gating signal will reach the comparator when the switch, S, in Fig. 14 is closed. This switch is the one mounted on the spindle of the rotating sector and which closes during the transitional periods when the light reaching the photocell comes from both long and short paths.

The voltage to be transformed by the comparator into a time delay is that to which the condenser, C, is charged when the output of the amplifier is fed into V5. The control grid of V4 and one plate of C are connected to H.T. through a large resistance and so are at approximately earth potential. Hence the voltage on C is the peak voltage of the output pulse from the amplifier.

At the same instant as C is charged up, the gating pulse from the lamp circuit is fed on to the grid of V1. Normally V1 is heavily conducting, causing a large voltage drop across the screen resistor of V2. Thus the anode voltage of V2, which is also the voltage on the cathode of V3, is high - higher than the voltage to which the anode of V3, along with the condenser C, is raised when the lamp flashes. Thus V3 is non-conducting and V4 is quiescent.

The gating signal cuts off V1 and so releases the screen grid of V2 and this valve then functions

as a Miller time-base, giving a linear run-down of voltage with time. The rise in screen voltage of V2 is differentiated and this sharp positive pulse is used as the first of the two measuring pulses.

Now consider the diode V3. Its anode is at the voltage which is to be measured and its cathode is tied to the anode of the Miller valve and falls linearly in voltage with time. Thus, at an instant determined by the voltage on C, V3 begins to conduct and C discharges causing a current to flow in the secondary of the transformer, T. This leaves a negative charge on the control grid of V4, lessening the current passing through the valve and the primary winding of T. This step in current is turned by T into a large negative swing on the cathode of V3 which, via C, cuts off V4 completely. This switching action takes place very rapidly. V4 can be regarded as a blocking oscillator which is triggered by the conduction of V3 and which is cut off in the first half-cycle of its operation. The second of the two measuring pulses is derived from a tertiary winding on the transformer, T.

The run-down of the Miller time-base continues beyond this point and must be made steep enough in relation to the rate of discharge of C in order to



(a).

Negative gate from
lamp circuit.

Anode of Miller
timebase.

First measuring pulse.

Rectified signal
from amplifier.

Production of
second measuring pulse.

The two measuring pulses.

(b).

Effect of a fall in HT voltage
on Miller rundown.

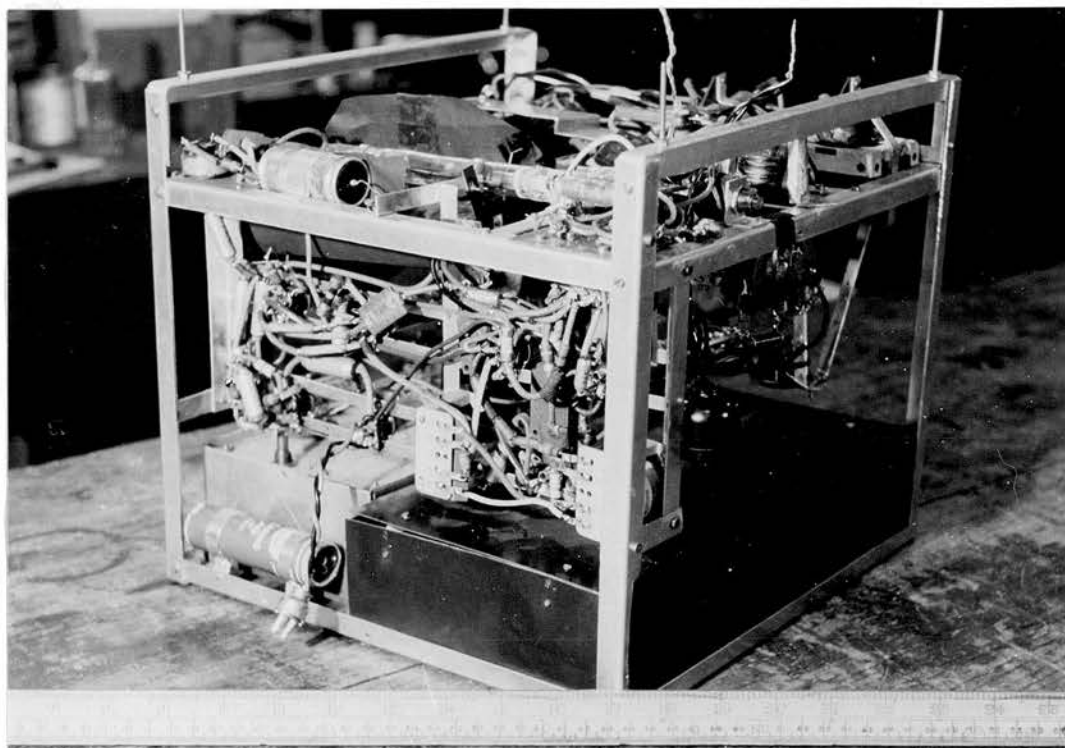
The time separation of the pulses
is unchanged if the reference voltage
falls in proportion.

Fig.16. Comparator Waveforms.

prevent V4 from recovering and giving rise to unwanted pulses. The Miller valve recovers at the positive-going edge of the gating pulse and is ready for the next voltage measurement. In the strobing action the condenser, C, loses sufficient charge to bring its voltage below that of the foot of the Miller run-down. This is actually more desirable than the complete discharging of C which was first envisaged, since it helps the rectifier, V5, to deal with the sharp pulses from the photocell amplifier.

The measuring pulses are subjected to diode mixing at the grid of V6 out of which they appear as sharp, uniform, negative pulses which are fed to the transmitter. The way in which the comparator circuitry is mounted on the radio sonde is seen in Plate 12.

Voltage waveforms at various points in the comparator circuit are shown in Fig. 16a. The comparator is insensitive to variations in the L.T. voltage supply, the filaments of V4 and V3 being run off the same battery (Williams and Moody 1946). The circuit is also self-compensating for changes in H.T. voltage if the voltage fed to the condenser, C, changes in equal proportion. Fig. 16b shows how this arises. Although full use of this property cannot be made, a



-Plate 12. -

Side view of the radio sonde showing the circuit components of the comparator.

certain amount of stabilisation is effected by running the comparator and amplifier off the same H.T. supply.

The question of the accuracy of the comparator is dealt with in a later chapter. It may be noted here, however, that the circuit described above could form the basis of a precision radio sonde, measuring pressure, temperature etc. The elements relating to these quantities could be made to vary the value of resistances forming part of a potentiometer chain across the comparator H.T. supply. The voltage at the middle of the chain, which would then relate to the pressure or temperature etc., could be fed on to the condenser, C, and transformed into a time delay between two pulses. This time delay would be independent of the variations in H.T. and L.T. voltages during a flight and would indicate the voltage on C with an accuracy of better than 1 part in 1000.

(b) The Telemetering System - (ii) the Transmission of pressure, temperature, and the measuring pulses.

Pressure and temperature are measured during an ascent in the same manner as in the Kew radio sonde (Dymond 1947). A pressure element is shown in Plate 13 where the steel aneroid capsule can be seen held



-Plate 13. -
A pressure element.



-Plate 14. -
A temperature element.

in a framework so that, when the bellows expand, they move a strip of mumetal closer to the core of an inductor, thus increasing the value of its inductance. A carefully-designed condenser and this inductor form the tank circuit of an audio oscillator whose frequency is thus controlled by the position of the bellows and so by the pressure of the surrounding air.

Changes of temperature affect the elastic properties of the aneroid capsule and the resistance of the windings of the inductor and also cause variations in hysteresis and eddy currents in the mumetal, and changes in permeability. In order to be able to apply corrections for these effects, the temperature inside the radio sonde has to be measured. This is done by an element, similar in design to the pressure element, but incorporating a bimetallic strip instead of the aneroid capsule (Plate 14). This strip is of ordinary and invar steel rolled into a cylinder 1 cm. in diameter which curls up with increase of temperature thus moving the mumetal strip.

An inductor is shown diagrammatically in Fig. 17. The core, A, consists of six mumetal stampings whose ends are turned up to form flat pole-pieces and the coils, B, are wound on plastic formers using 38 S.W.G. copper wire. The moving mumetal armature, C, is supported by a nickel silver stamping, D, one portion

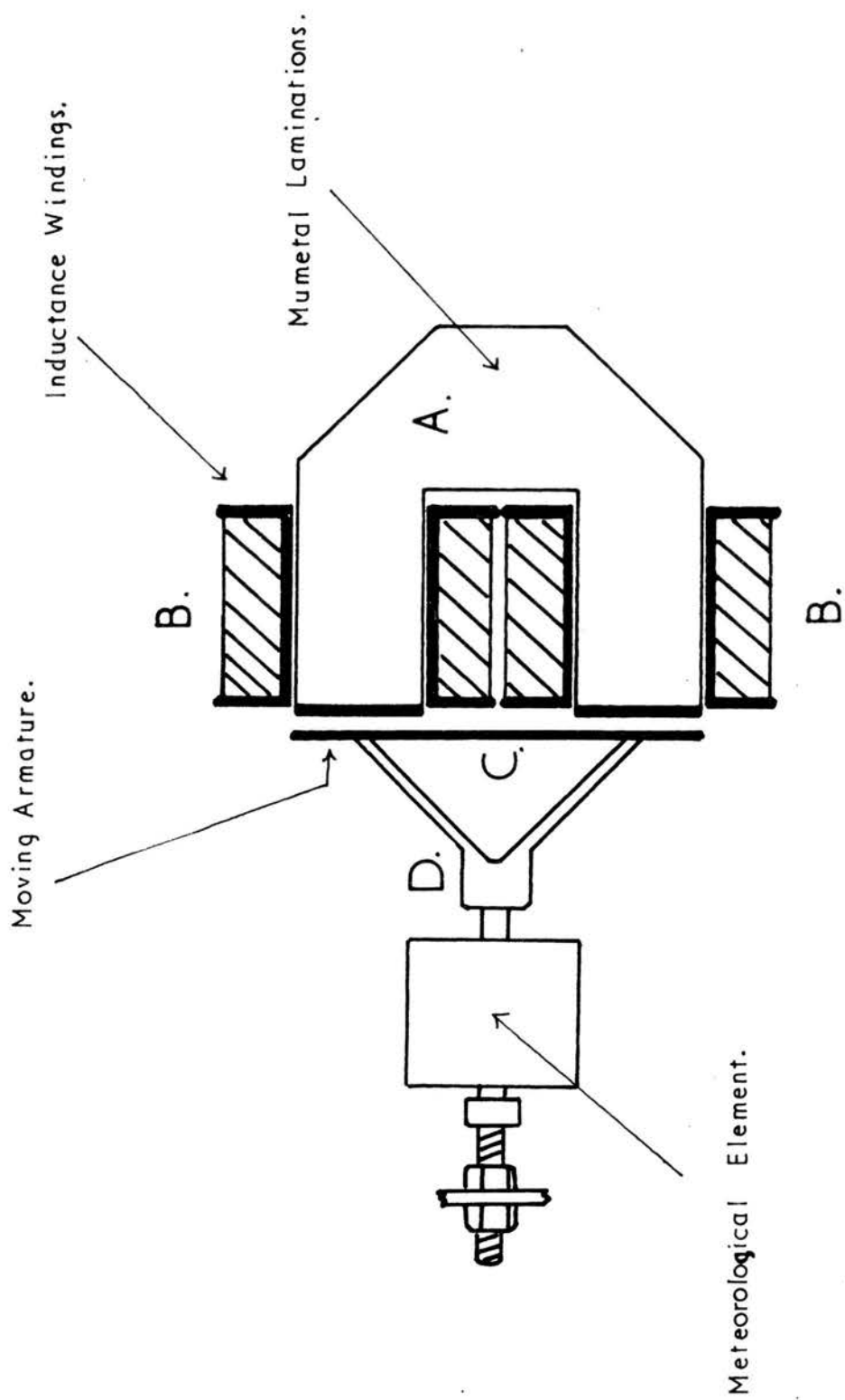


Fig. 17.
Diagram of Inductor.

of which serves as a spring hinge for the armature.

The temperature and pressure inductors are switched alternately into the circuit of the audio oscillator by means of the switch described earlier in this chapter (section (a), part (iii)). The circuit of the audio oscillator, buffer stage, modulator and transmitter is seen in Fig. 18. The audio oscillator is of the Hartley type with a frequency range of 700 to 1000 c./s. The .07 mF condenser which, together with one of the inductors, forms the tank circuit of the oscillator, is of a clamped mica type with a very low temperature coefficient of capacity (of the order of 30×10^{-6} per $^{\circ}\text{C}$). The circuit is carefully designed to be almost completely unaffected by small fluctuations in battery voltages.

During a flight, the pressure frequency changes by about 200 c./s. with a sensitivity of about 1 c./s. per 8 mb. near the ground and 1 c./s. per 3.5 mb. at high altitudes. The frequency corresponding to temperature varies at a rate of around 1.7 c./s. per 1°C over a large range of temperature.

The timing pulses are added to the A.F. signal at the grid of the buffer stage which isolates the A.F. oscillator from the H.F. circuits in the interests of stability. The potentiometer chains at the grid of the buffer are arranged so that in the eventual

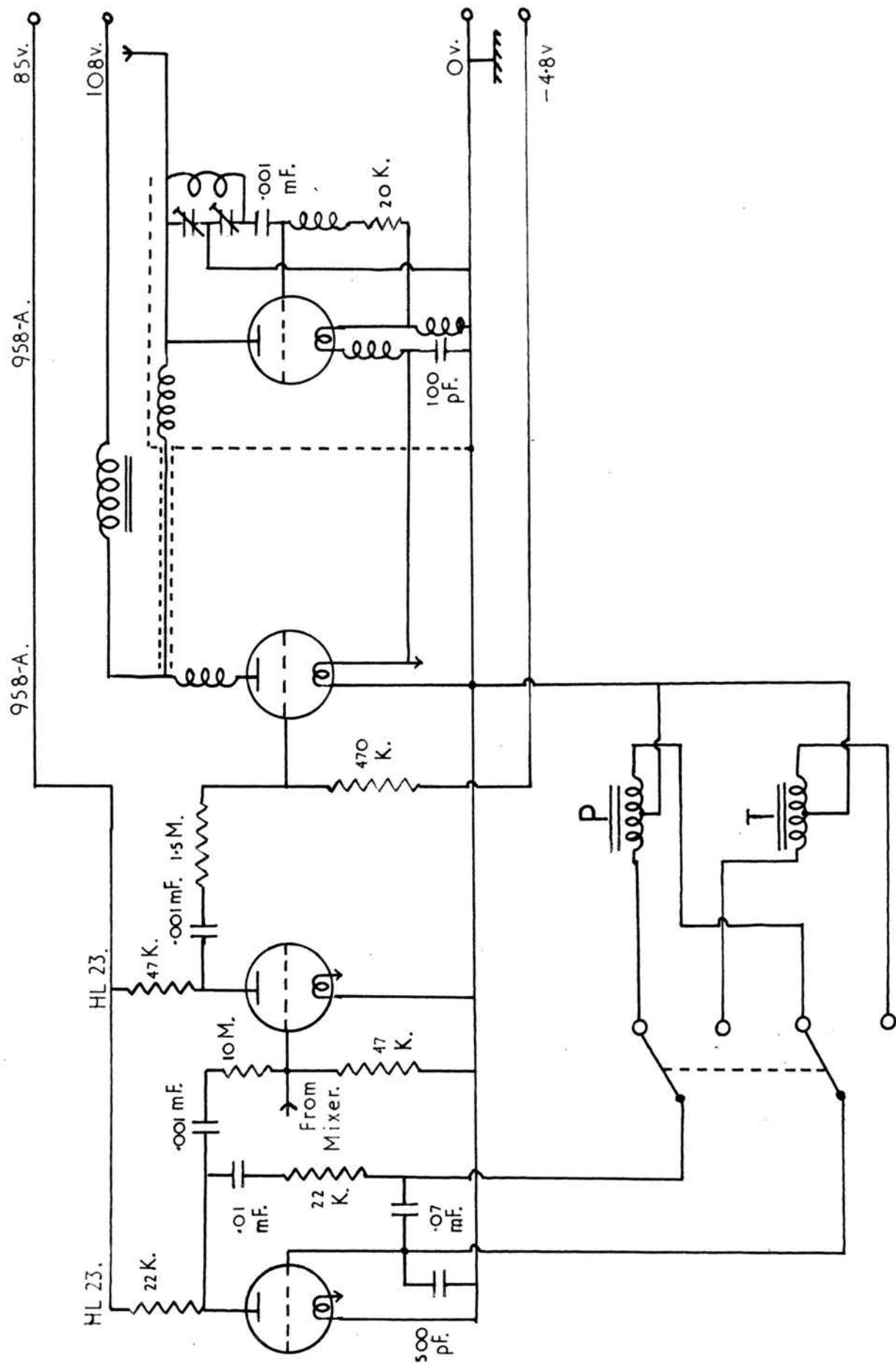


Fig.18. Circuit of A.F. Stages, Modulator and Transmitter.

transmission, the modulation depth of the timing pulses is larger than that of the A.F. oscillations, thus providing a simple means of separating the two signals at the receiving station.

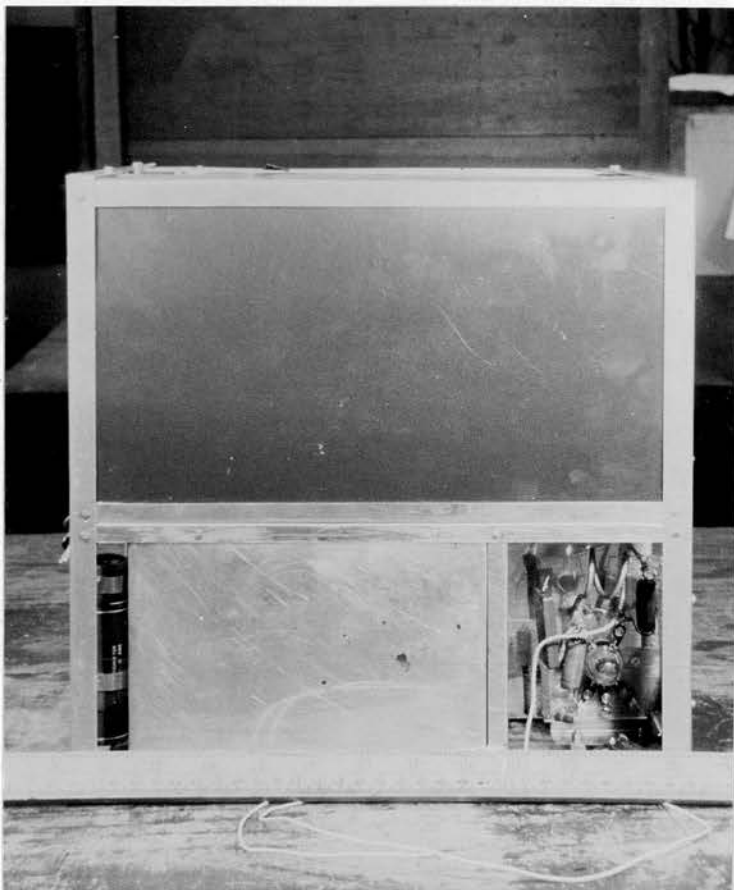
The transmitter first used was the same as that in the Kew radio sonde and is described in Chapter 7. After two trial flights it became clear that this was not going to give signals strong enough in relation to the general noise on the 30 Mc./s. band to enable the ozone radio sonde to function efficiently at high altitudes. The intensity of noise due to electrical interference is very high at this frequency and the only solution was to transmit at another frequency where the noise level was lower.

At the time this decision was taken, a colleague, Dr. R.P. Thatte, was in the process of completing a radio receiver for the 150 Mc./s. band allocated to the Meteorological Service and Experimenters. It was decided to adopt this new frequency for the ozone radio sonde and to collaborate with Dr. Thatte in the erection of new receiving aerials and in the development of a suitable transmitter^{*}, the final form of which is seen in Fig. 18.

* Dr. Thatte was engaged in the production of a balloon-borne apparatus for the study of cosmic rays. His loan of the 150 Mc./s. receiver was much appreciated.

The H.F. oscillator consists of an acorn triode (958-A) in a Colpitts circuit and it is anode-modulated by a second acorn triode on to whose grid are fed the measuring pulses and the A.F. signal. The transmitting coil consists of two turns of 10 S.W.G. tinned copper wire and is 1 inch long and 1 inch in diameter. The aerial is an end-fed half-wavelength dipole, length 36.7 inches, directly coupled to the anode end of the transmitting coil. Tuned H.F. chokes are used in the H.T. lead, filament leads and in the grid circuit. These consist of 1 inch long coils containing 33 turns of enamelled copper wire, the diameter of the coils being $\frac{3}{8}$ inches.

The transmitting stage is mounted by itself on a Perspex support and the layout of the circuit is very critical. The shortest possible leads are used throughout and, in the case of the tuned L.C. circuit, this is effected by having the trimming condensers embedded in the Perspex with the ends of the coil soldered directly on to them. As can be seen from Plate 15, which shows the base of the apparatus, the transmitter is so placed that the aerial can emerge directly from the underside free of any damping effects from other parts of the instrument. The transmitter is well screened from the rest of the apparatus and a screened lead connects it to the



-Plate 15. -

The under-side of the radio sode. The transmitter is seen together with the bases of the amplifier and the battery container.

modulator stage. Another view of the instrument is shown in Plate 16 in which the shielding round the transmitter is clearly visible.

This simple transmitter circuit produces both amplitude and frequency modulation. Its effectiveness greatly depends on the design of the A.F. choke in the H.T. supply lead. This choke is made up with 34 S.W.G. enamelled copper wire wound on a hollow cylindrical Tufnol former of diameter $7/16$ inches and length $5/8$ inches; the diameter of the whole coil including the windings is $1\frac{1}{8}$ inches. Mumetal laminations in the form of E^S and I^S are fitted to form the core.

A thermal milliammeter whose terminals bore quarter-wavelength stubs gave a reading of 70 mA when placed near the transmitting aerial, thus indicating a radiated power of 400 mW. Due to shunting effects at the high frequency, this meter would read low and so the power was probably near the 600 mW rating of which the valve is capable. For quick checks to see whether the transmitter is functioning properly it is convenient to replace the meter by a small 1.4 volt bulb. When the dipole, with the bulb filament at its centre, is held near the aerial, the bulb shines brightly.

(c) The Power Supplies.

During the design of the apparatus described above, it was continually borne in mind that the power available would be limited. The number of valves was kept to the absolute minimum necessary for the efficient working of the radio sonde and the most economical types were used. Nevertheless, when the arrangement of the power supplies was considered, it became clear that these were going to comprise a large fraction of the total weight of the instrument.

The L.T. requirements were:-

0.2A at 1.25 volts for the valves in the transmitter
and modulator stages.
0.4A at 1.4 volts for the valves in the comparator.
1.1A at 1.5 volts for the lamp filament.
0.1A at 2.0 volts for the valves in the A.F. oscill-
ator and buffer stages.
0.2A at 2.4 volts for the motor.
0.35A at 6.3 volts for the valves in the amplifier.
0.1A at 1.4 volts for the rectifier valve. To come
from an independent battery.

The H.T. requirements were:-

3.8 mA at 48 volts for the comparator }
5.9 mA at 120 volts for the amplifier }

These had to be supplied by the same battery.

1.5 mA at 85 volts for the A.F. oscillator and buffer stages.

11 mA at 108 volts for the transmitter and modulator stages

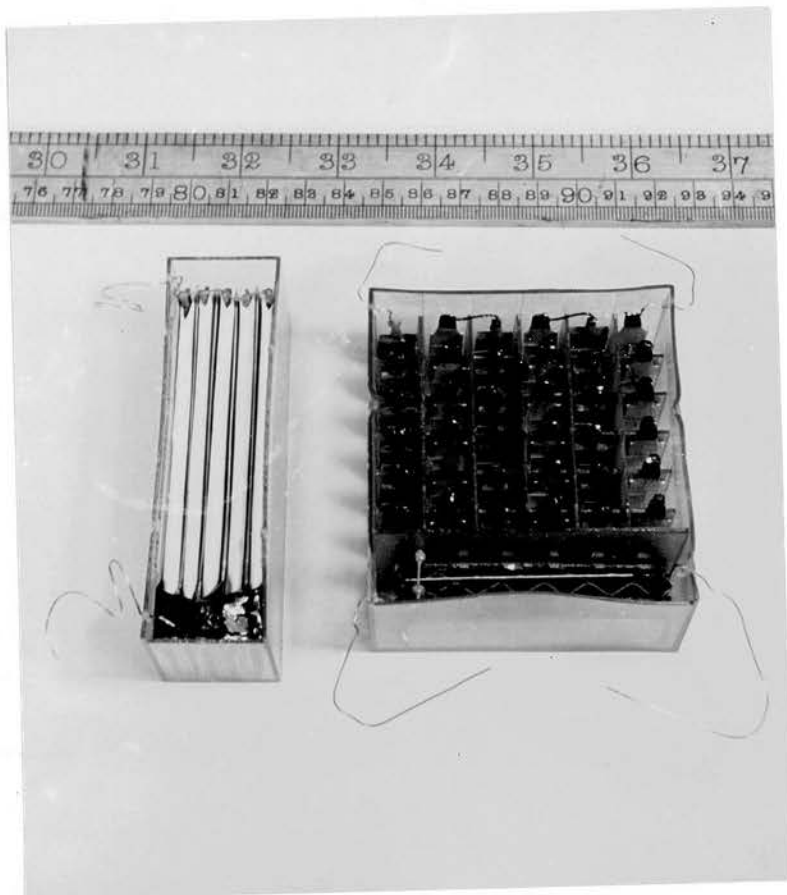
<0.5 mA at 190 volts for the lamp.

-4.8 volts and -7.2 volts for grid bias.

These last items had to come from a different battery to the one supplying the comparator and amplifier.

There were two suitable types of battery readily available and these are shown in Plate 17. They are made by the Barnard Accumulator Co. and the larger, known as the Mark I, combines an H.T. and an L.T. supply and is the type used by the Meteorological Office. The other is a Mark III L.T. unit and is really a more powerful version of the Mark I L.T. section.

Both the H.T. and L.T. cells are constructed with lead peroxide positive plates and amalgamated zinc negative ones and are contained in moulded cases of cellulose acetate. The electrolyte is sulphuric acid of S.G. 1.27 with the addition of about 1 per cent of mercuric sulphate. This last item provides a freshly amalgamated surface at the moment of use, the mercury originally on the zinc electrode diffusing



-Plate 17. -

A Mark 111 battery unit (left) and a Mark 1 unit (right).

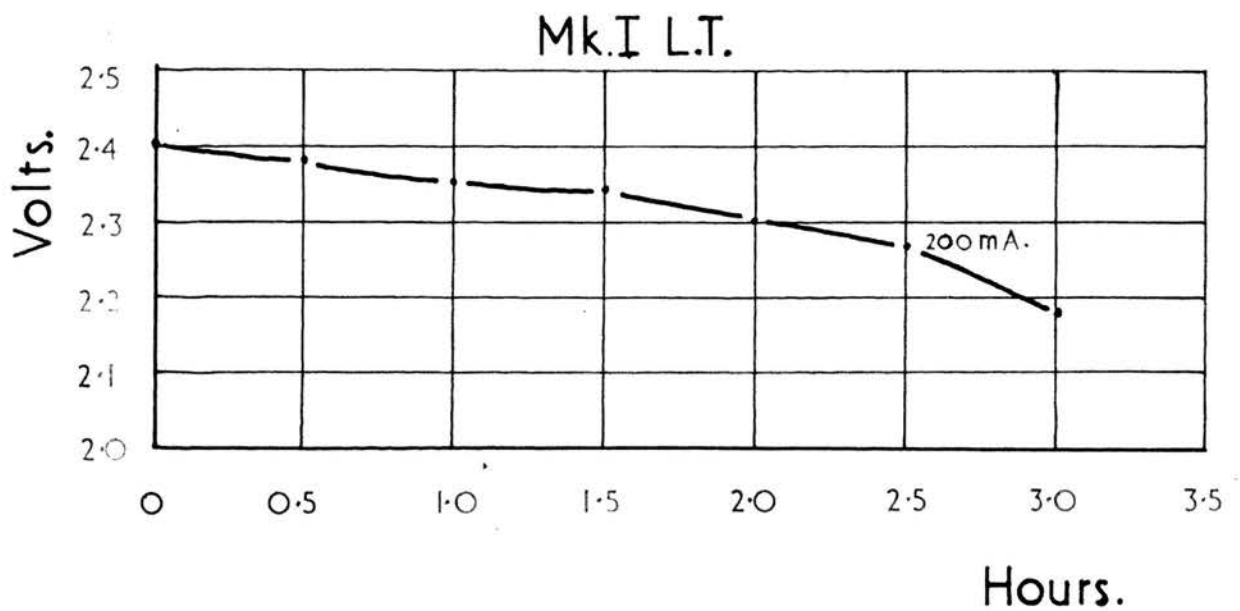
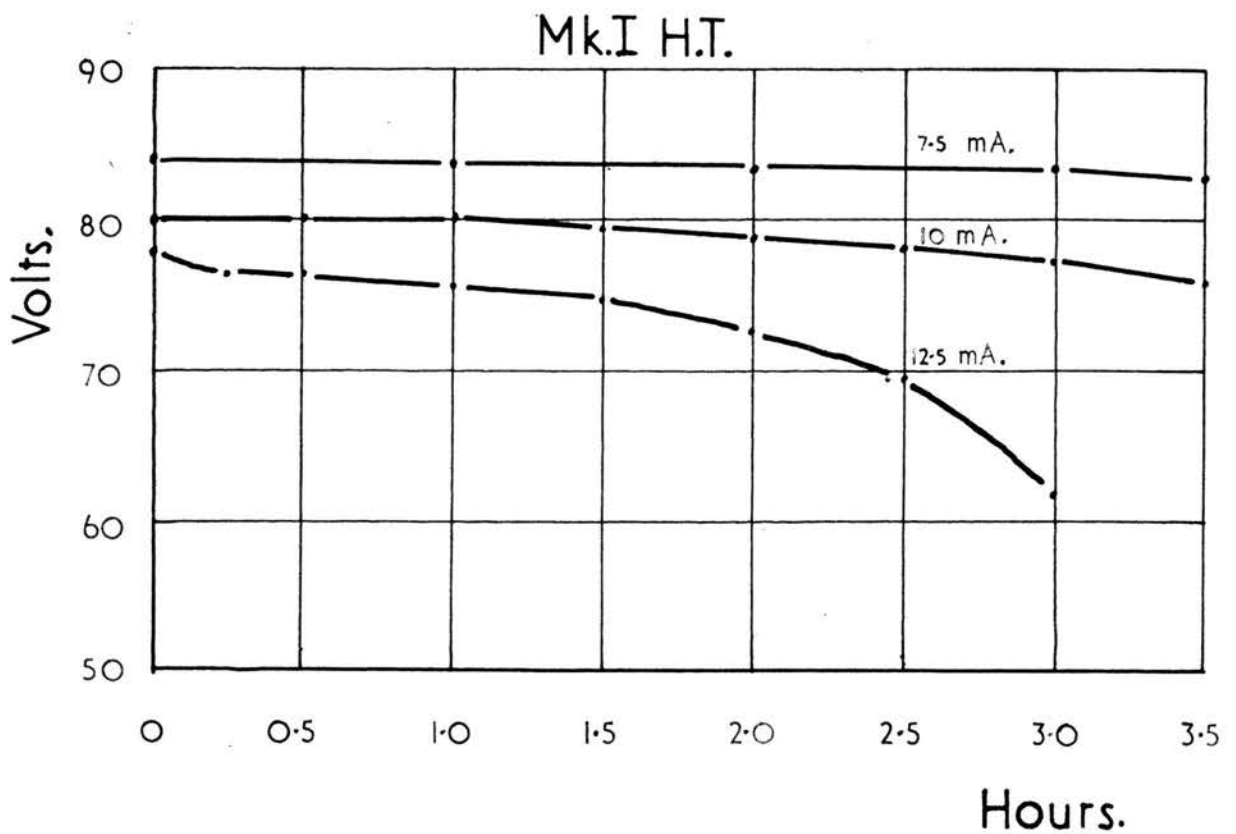


Fig. 19.

Battery Performance.

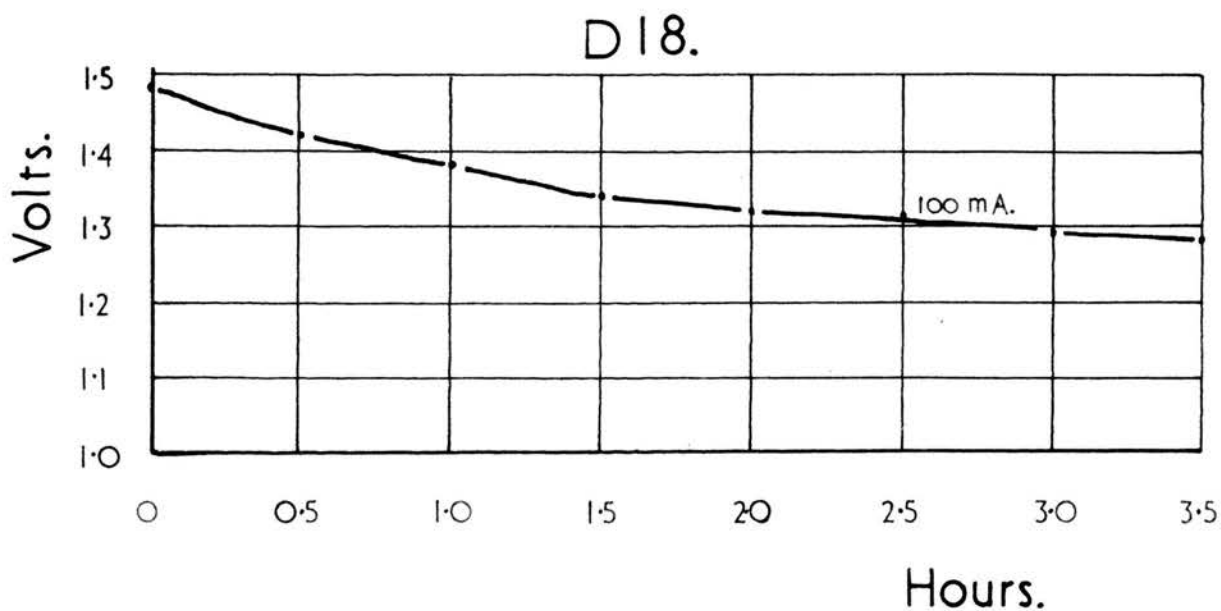
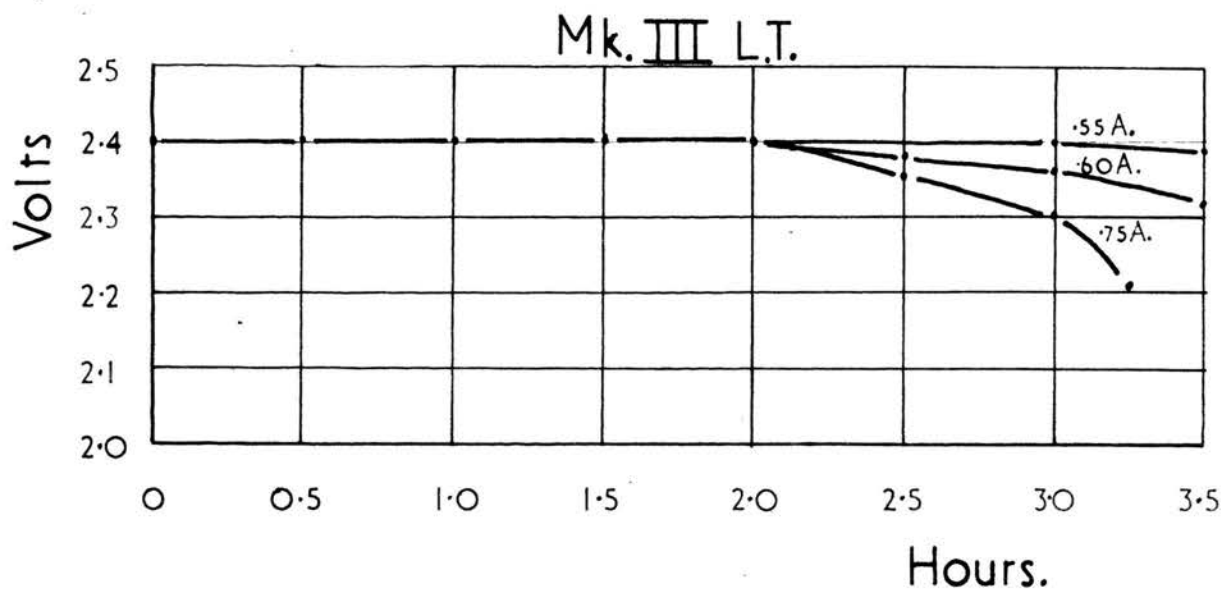


Fig. 20.

Battery Performance.

into the body of the metal during storage.

Each individual cell of the H.T. unit has to be filled separately with electrolyte using a large fountain pen filler. To prevent the acid spilling during a flight and causing short-circuiting between cells, a thin film of heavy oil is poured over the whole battery. The additional precaution is taken of painting the tops of the negative electrodes to ensure that there is no possibility of any part of the zinc surface being exposed to both air and acid since, under these conditions, a chemical action may take place which could eat through the plate completely. The batteries are filled about one hour before use in order to reduce the time taken for the internal resistances to fall during the discharge.

The voltage characteristics of the various batteries at different discharge rates, are shown in Figs. 19 and 20 and the following table summarises the battery performances and emphasises how much more efficient the specially-designed Barnard batteries are than a conventional dry battery such as the Ever Ready D18.

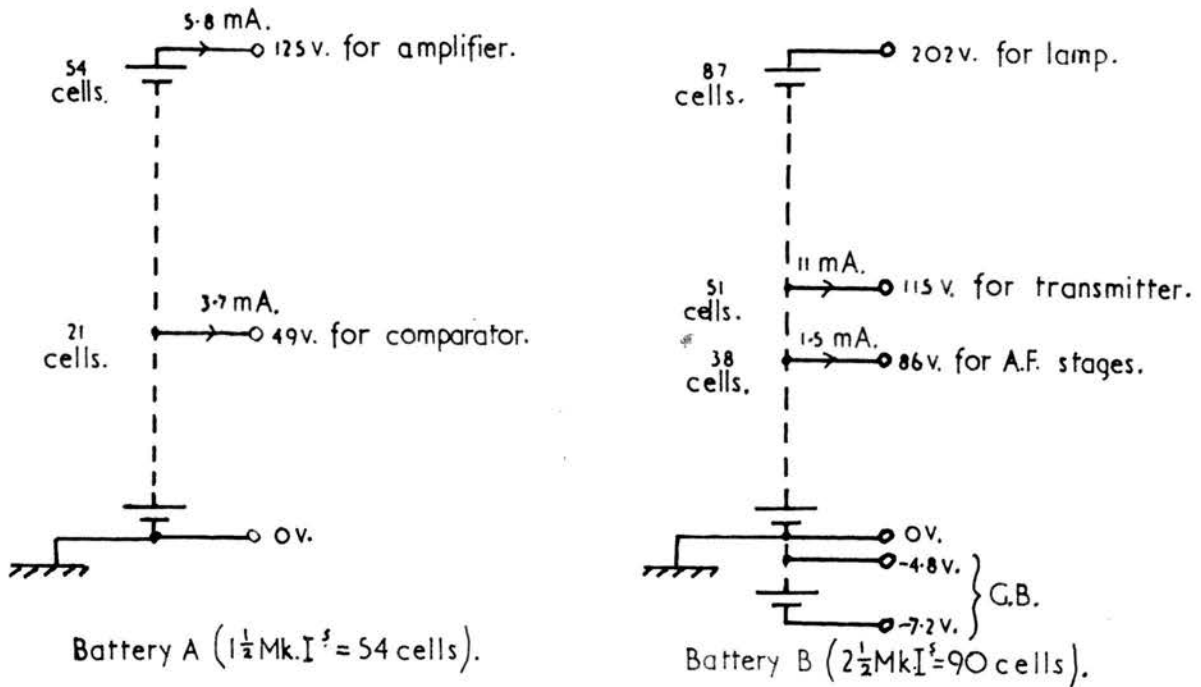
The power supply for the instrument is made up of four Mark I combined H.T. and L.T. units and four Mark III L.T. units. One Mark I H.T. section is

Battery type	Weight full (Gm.)	Voltage (Volts)	Discharge rate (mA).	Time for a 5% drop (Hrs).	Capacity/Weight (mW.-Hrs./Gm.)
Mk. I. H.T.	210	80	10	3½	13
" L.T.	90	2.4	200	2¼	12
Mk. III. L.T.	185	2.4	600	¾	29
D18	70	1.5	100	¾	2

converted into two separate batteries by re-arranging the way in which the cells are inter-connected. To avoid having large potential differences between adjacent rows of cells, the two negative terminals are situated in the centre of the moulding and thus the two positive terminals are at the ends of the two outside rows.

The H.T. supply can then be in two separate parts, one, part A, made up of 1½ Mark I^S and the other, part B, of 2½ Mark I^S. The tapping points for the various H.T. voltages required are shown in Fig. 21a which also indicates the discharge rates. As shown in Fig. 21b the L.T. sections of the four Mark I units are used to provide part of the L.T. power

(a) H.T.



(b) L.T.

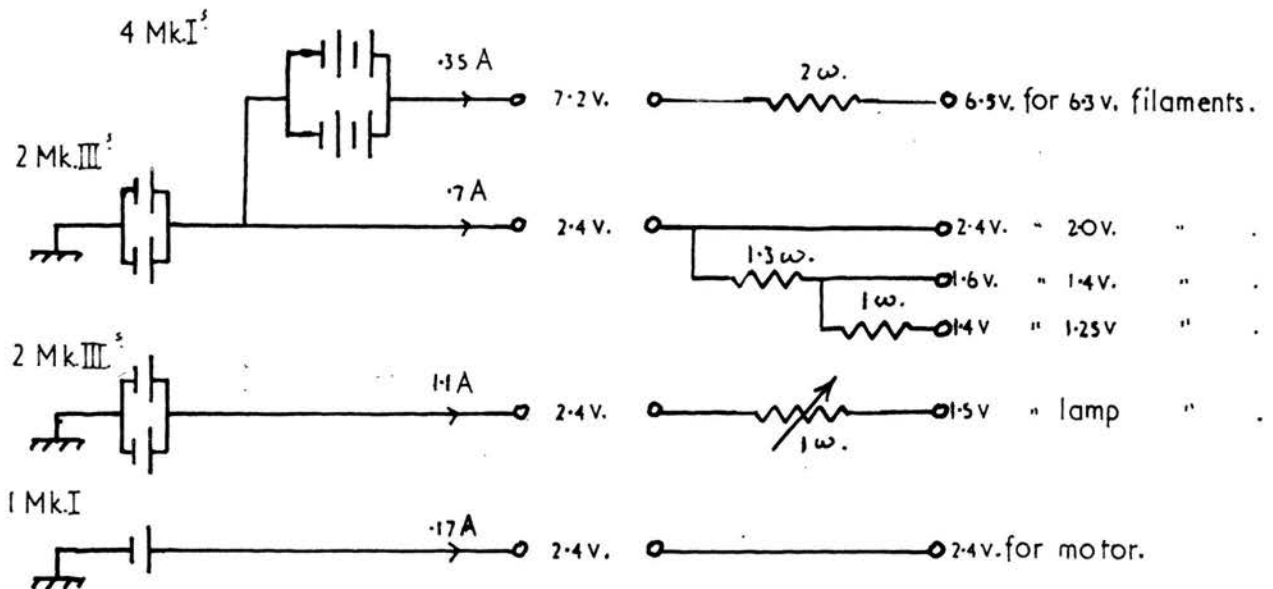
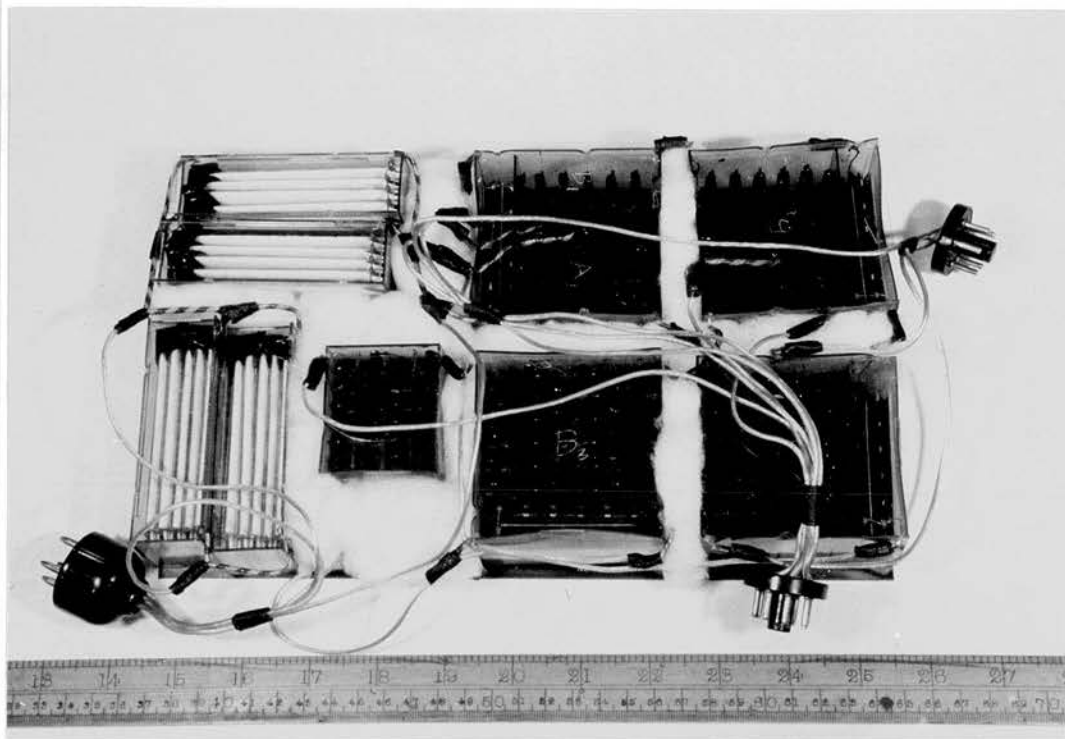


Fig. 21.



-Plate 1A.-

The batteries used in Flight IV. The small H. T. unit in the centre boosted the H. T. supply for the lamp. It was not required for the lamp used in Flight V.

required while the separate Mark III cells provide the remainder.

Voltage dropping resistors are required to obtain all the various L.T. supplies. Nominal values for the resistances are shown, the actual values being obtained by using different lengths of Nichrome wire wound on insulating formers until the required voltages are obtained. In arranging the tappings in Fig. 21 the tendency, wherever possible, was to make the voltage larger than necessary and so allow for any drop during discharge. The following table indicates the magnitudes of the decreases after 2 hours and after 3 hours. (See page 64a).

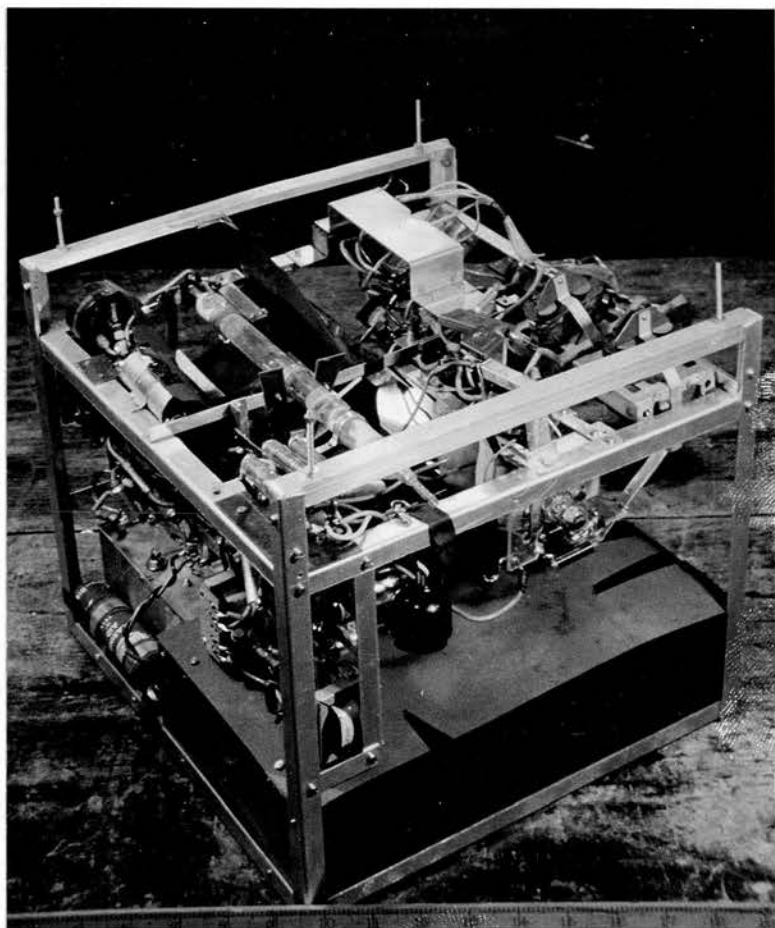
All the batteries fit into tight-fitting recesses in a paxolin tray and so are prevented from coming into contact with one another and causing short-circuits. The battery unit is seen in Plate 18 where part of the absorbent packing is also visible. The total weight of the unit with the batteries filled is 2½ Kgm. Three separate connector plugs are used for battery A, battery B and the L.T. supplies so preventing any interaction through common earth connections. In fact three different earthing connections are embodied in the L.T. side alone since, with currents of the order of 1 amp., contact resistances are by no means negligible.

Item	Initial Voltage	Voltage drop	
		after 2 hours (volts)	after 3 hours (volts)
Amplifier H.T. } A	125	1.3	2.1
Comparator H.T. }	49	0.7	1.6
Lamp H.T. }	202	7.5	22
Transmitter H.T. } B	115	7.3	21.5
Audio Stages H.T. }	86	5.8	17.5
Amplifier fils. }	6.5	0.2	0.4
Lamp fils. }	1.5	0	0
Other fils. }	2.4, 1.6, 1.4	0	0
Motor }	2.4	0.1	0.2
Rectifier fil. from D18.	1.5	0.16	0.19

The whole tray can be lifted bodily and inserted into its position in the battery container on the radio sonde. This is made of paxolin (Plate 19) and is sufficiently large to allow a layer of cellulose wadding to be put round the batteries. When the instrument lands after a flight it may lie at any angle and this wadding absorbs much of the acid which would otherwise spill and cause much damage to the rest of the instrument. The position of the rectifier battery can also be seen in Plate 19. It lies in a small space behind the main battery container and is carefully insulated from the chassis since the rectifier filament is directly connected to the strobing condenser which must be able to hold its charge, without any leakage, to give the necessary accuracy in telemetering.

In preparing the radio sonde for a flight, all work such as the testing of the electronics, calibration of the meteorological elements etc. is done using accumulators and 120 volt dry batteries for the power supplies. By incorporating rheostats in the L.T. supplies and grid bias batteries in the H.T. lines, the same voltages as those produced by the airborne power pack can be supplied to the apparatus through identical connecting plugs. This enables the apparatus to be brought into a condition which makes only the minimum

of adjustment necessary when the actual flight batteries are connected immediately prior to an ascent with a resultant increase in the life of these batteries during the actual flight. For convenience the heavy earthbound batteries are mounted on a trolley which can easily be moved to wherever the radio sonde is situated.



-Plate 19. -

The space for the battery tray. The rectifier battery is in the far left hand corner of the base.

(d) Heat Insulation.

All the different sections of the radio sonde are mounted on an aluminium framework which can be fitted inside a very light heat-insulating container. Two different materials were tried for the construction of this container - 'Onazote' and 'Aero Jablex'. The former consists of sheets of expanded ebonite and the latter of sheets of expanded polyvinyl chloride.

'Onazote' has one unfortunate quality which limits its use; newly-made or newly-cut sheets of this material give off sulphurous fumes which corrode any metalwork near at hand. Soldered connections are destroyed and nuts and bolts rusted together. The effect wears off with time and, provided it is made up into the box-shape a few months before use, 'Onazote' is ideal.

'Aero Jablex' is almost twice as expensive and does not have so smooth a surface as 'Onazote' and so is more difficult to slip on to the radio sonde. The 'Commercial Rigid' variety used was found to warp slightly, causing the sides of the box to become misshapen with standing. The 'Aero Jablex' boards, however, do not give off corrosive fumes and are much more pleasant to handle.

Both types of boards were tested to see how they

reacted to low pressures. There was no effect on either thus showing that they do not contain closed cells which blow out when the outside pressure is lowered. Both materials are claimed by their respective manufacturers to have densities of around 4 lbs./cub. ft. and thermal conductivities of 0.2 B.T.U./sq. ft./hour/inch/[°]F. These correspond to figures of 0.06 gm./cub. cm. and 7×10^{-5} cal./cm²/sec./cm./[°]C in metric units.

In practice an 'Aero Jablex' box was used for one flight and an 'Onazote' one for another. Both boxes were made from 1 inch thick sheets jointed together and made secure with 'Bostik Sealing Compound 692'. For identically-sized boxes with external dimensions 14½ inches square by 13 inches high, 'Aero Jablex' weighed 2.3 Kgm. and 'Onazote' 2.0 Kgm.

After the first trial flight it was decided to cover the boxes with double layers of 'Cellophane', 0.001 inches thick. By this means an insulating layer of air surrounded the box and helped to 'trap' some of the heat from the sun. An 'Aero Jablex' box covered with two 'Cellophane' shells 1 inch apart is shown in Plate 20 in which can be seen the windows which transmit the light traversing the absorption path in the outside air.

As described earlier these windows are made out



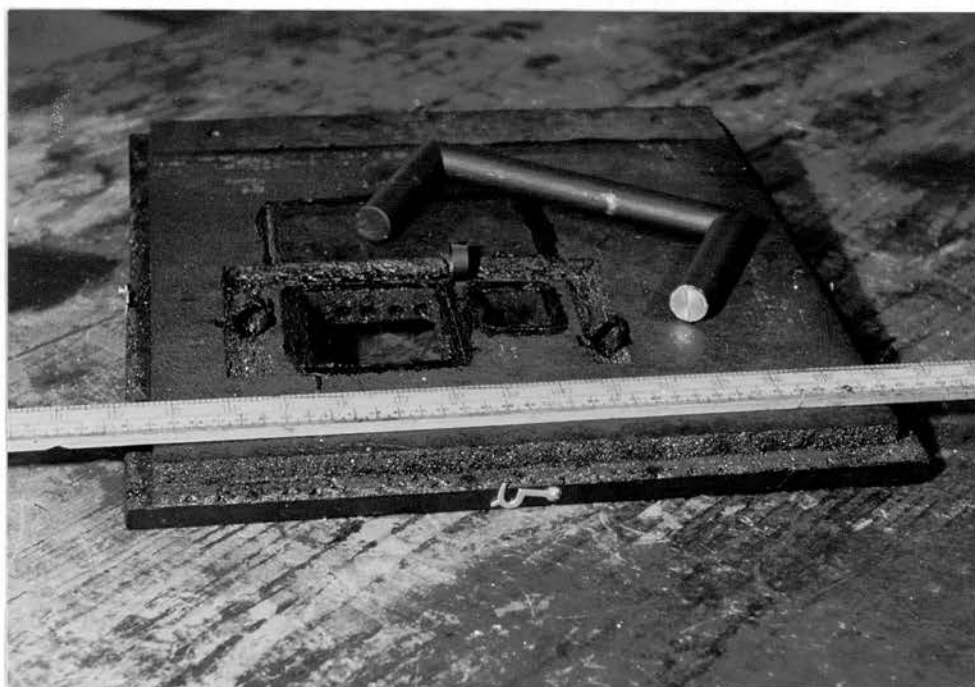
-Plate 20. -

Container for the radio sonde. The windows,
reward label and " Cellophane " covering can
all be seen.



-Plate 21. -

The lid of the container showing the cell which holds the drying agent and which is connected to the windows by means of a number of vents.



-Plate 22. -

The under-side of the container lid together with the tube for heating the windows.

of 2 mm. thick sheets of a special glass. The window for the lamp is 3 inches square and that for the photocell $1\frac{1}{2}$ inches square. Since the temperature outside the box may be 80°C lower than that inside during an ascent, a single window would become obscured with moisture from the batteries and filter condensing on its inner surface which would be very cold. To try to prevent this condensation occurring, the windows were made double and the air in the 1 inch space between the two plates of glass was dried by having a quantity of silica gel in the walls. Plate 21 shows the upper surface of an 'Onazote' lid with a cavity which can be filled with the drying agent and which is open to the air between the double windows through a number of connecting holes containing loosely-packed cotton wool. The cavity and its lid are made water-proof by waxing their inner surfaces and so the contents only affect the air between the windows.

The white marks at the sides of the windows are used in connection with the alignment of the nine mirrors on the top triangle. The brass terminal near the metre-stick is used to form an external connection in the L.T. supplies which thus need not be discharging during all the adjustments before a flight.

In some of the photographs of the radio sonde,

e.g. Plate 19, four long bolts may be seen projecting upwards from the four top corners of the aluminium framework. These bolts pass through holes in the container lid and are secured to two struts on the lower triangle. The lid is thus sandwiched between the struts and the top of the radio sonde. The rest of the insulating box can then be pulled up over the body of the sonde and secured by brass hooks to the lid. During this process the aerial wire is pulled through a hole in the foot of the box to hang down below the instrument. It is then tied to a supporting rod which is fitted into a socket in the base of the box. This rod consists of a spiral roll of stiff paper which makes a light but rigid support.

When the radio sonde is in its container the only way in which stray light can reach the photocell is through the small $1\frac{1}{2}$ inch square double window in the container lid. Since the light can only reach the photocell by passing through the filter which is $6\frac{1}{2}$ inches below the windows, the effect is as if the sensitive surface of the photocell were situated at the foot of an $11\frac{1}{2}$ inch long circular shaft of diameter $1\frac{1}{4}$ inches. This means that the only effective stray light is contained in a cone of angle 12° ; this, in turn, means that this light must pass through an area of just under 1 sq. metre at the

top triangle, 5 metres from the photocell. The photocell always points at the top triangle and hence, if necessary, a screen could be mounted there which would cut out all stray light.

For the second ozone-measuring flight it was decided to take the additional precaution of heating the windows. Room could have been found for an additional Mark III L.T. cell, but the available power of just under 2 watts was inadequate to heat the whole surface area of the windows. No simple chemical action was known which would give out only a moderate amount of heat and which did not require oxygen for its action.

A type of resin mixture, used in the laboratory for 'potting' circuits comprised of miniature components, was known to give out heat during the setting process. The action does not require oxygen, is not accompanied by the release of any gas or fumes, and is controllable by the variation of the relative weights of the ingredients. The polyester resin used is known as 'Marco resin S B 280' (Parkyn 1951) and a typical formula to give a setting time of about 40 minutes is:-

Marco resin S B 280	100	parts	by	weight
H.C.H. catalyst	4	"	"	"
Styrene monomer	5	"	"	"
Accelerator E	4	"	"	"

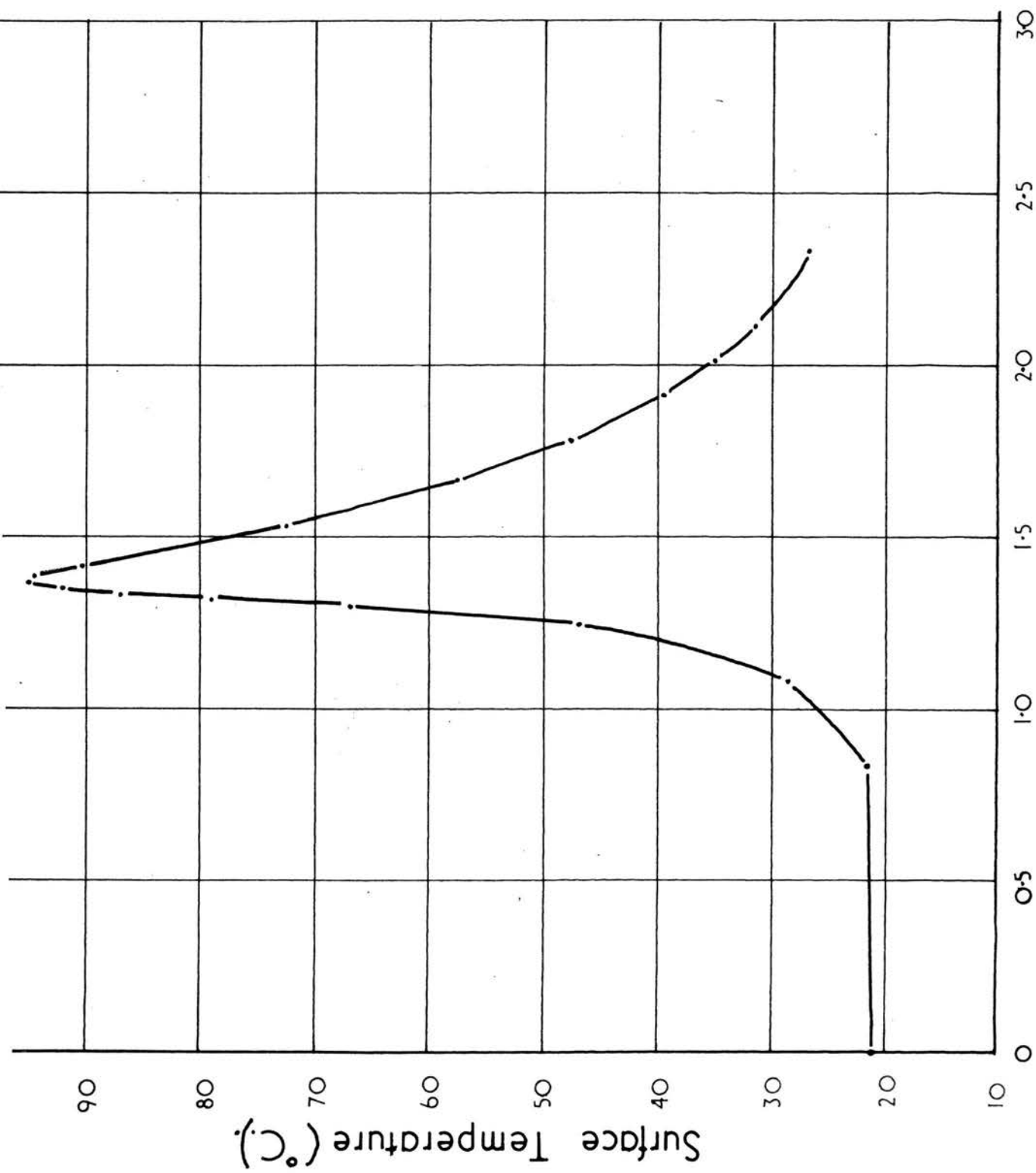


Fig.22. Heater Characteristic.

The variation of setting time with accelerator content can be seen from the following table which refers to the above concentration of resin, catalyst and monomer:-

Accelerator content in 100 parts of resin	4	3	2	1	.5	.4	.3	.2	.1
Setting time (mins.)	40	60	80	120	180	210	270	330	840

With the lower accelerator contents the setting process does not start for a considerable time after mixing and the heat of polymerisation is given off gradually without a large rise in temperature. Tests were carried out to find a suitable formula for a resin which could be poured into a tube surrounding the windows and which would give off a sufficient amount of heat at the right time to prevent any condensation. Fig. 22 shows how the temperature of the surface of a brass tube containing resin mixed to the selected formula, varies with time after mixing. The proportions were

Resin	100	parts	by	weight
Catalyst	4	"	"	"
Monomer	5	"	"	"
Accelerator	2	"	"	"

and they were mixed in that order. It is seen that the temperature reaches 40°C , 70 minutes after mixing and remains above 40°C for a further 45 minutes.

Although it would have been better to have had a lower maximum temperature for a longer time, it was desirable to keep the time between mixing and heating up as small as possible since the exact time of release of the balloons could not be predicted much in advance. However, it was reasoned that if the heater could keep the windows warm in the initial stages of the ascent, they would remain clear even if the heater then ceased to function since, by that time, the pressure of the air between the windows would have become low.

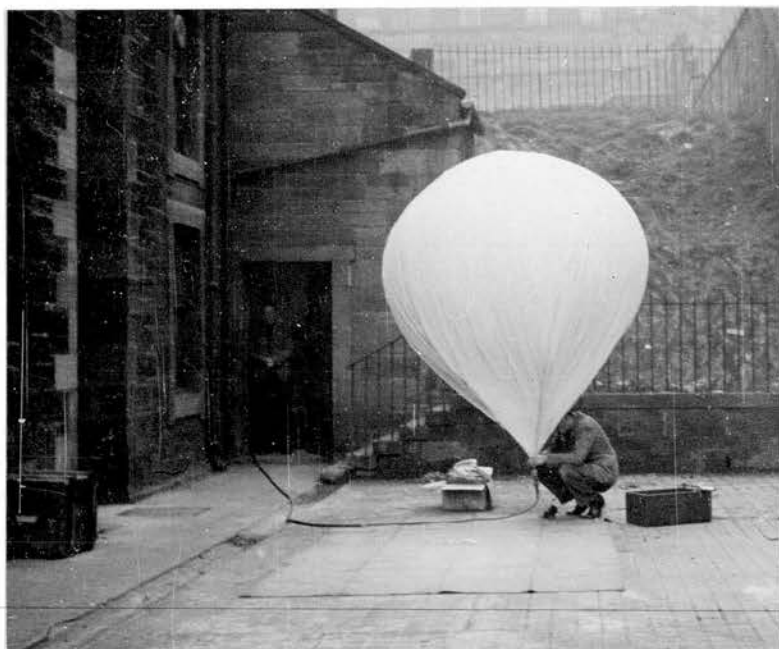
The brass heating tube is seen in Plate 22. It clips into a shallow trough round the windows and is painted matt black to avoid throwing any reflections into the photocell. The main tube is 6 inches long with 3 inch arms; the brass tubing is $\frac{4}{5}$ inches in diameter with walls $\frac{1}{32}$ inches thick. One end is sealed and the other has a cap which can be screwed on to prevent any liquid escaping.

(e) The Balloons and Rigging.

Two types of rubber balloons were used during the series of flights. For the initial tests the small 700 gm. balloons used for ordinary radio sonde work were employed. With a free lift of 1 Kgm. this size of balloon can take a load of 2 Kgm. to around 70,000 ft. (21 Km.). At this height the rubber, now very thin, is perished by the intense cold and by ozone.

For the flights with the complete ozone radio sonde, larger balloons made of much thicker rubber were used. These weighed $4\frac{1}{4}$ Kgm. each and had a diameter of 6 feet at ground level. A balloon of this type can be inflated to carry a load of 3 Kgm. with a free lift of 1 Kgm. This gives a rate of ascent of about 1000 ft./min. which is high enough to allow heights greater than 90,000 ft. (27 Km.) to be obtained on the majority of occasions.

The actual balloons used were from the same batch as used by Pullar and Dymond (1953) in a series of flights during which heights greater than 100,000 ft. (30 Km.) were often reached and, on one occasion, a height of 124,000 ft. (37 Km.) was recorded (Herz and Tennent 1953). The cosmic ray measuring apparatus in these flights required the lift of two balloons whereas the heavier ozone equipment needs that of



-Plate 23. -

A 4½ Kgm. balloon being filled. Note the canvas sheet on the ground and the rubber hose running to the hydrogen cylinders inside the building.

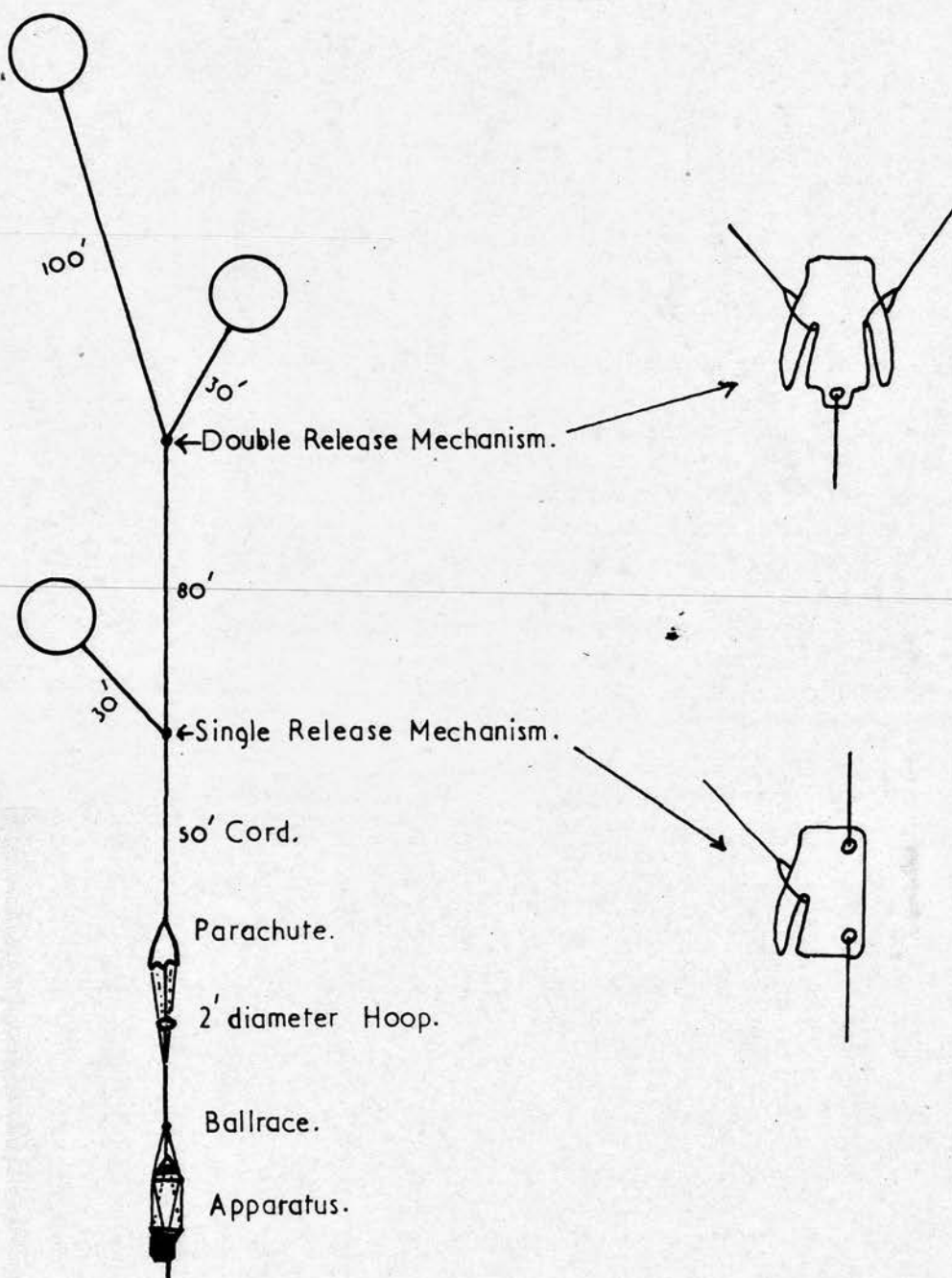


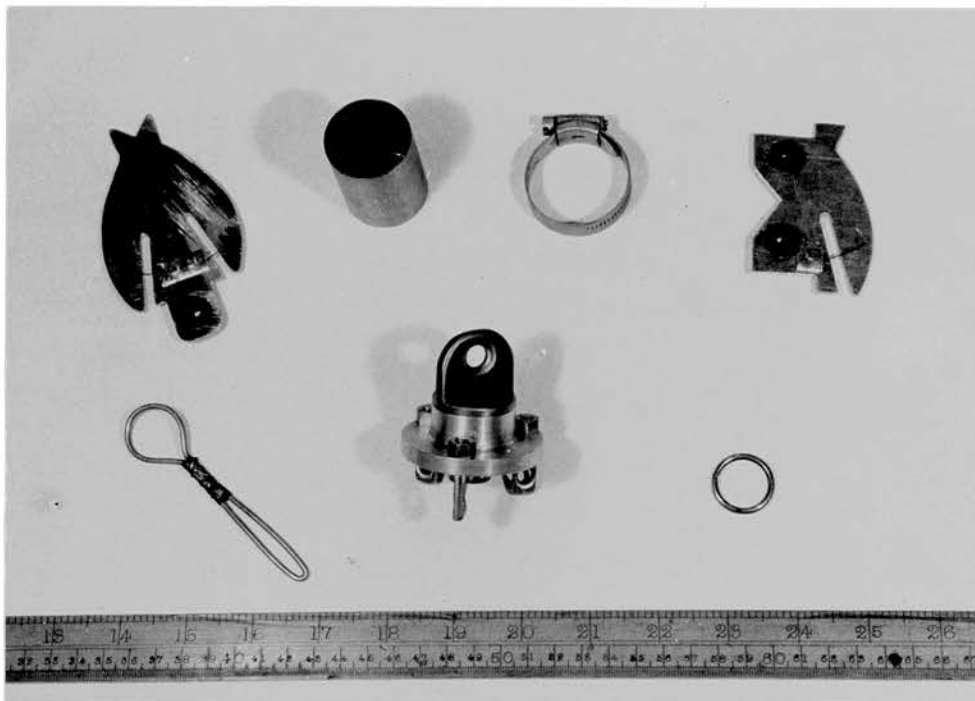
Fig. 23.

The Balloons and Rigging.

three balloons, thus slightly reducing the chances of exceeding 100,000 ft.

The balloons are filled in a sheltered corner of the yard outside the laboratory, using hydrogen gas from cylinders. A length of rubber hose is used to avoid having to manhandle these cylinders from their rack inside the building. The gas from five 165 cub. ft. cylinders is required to fill the three 4½ Kgm. balloons and the process takes about 1½ hours. A canvas sheet is laid on the ground during filling thus avoiding any possibility of the balloon rubber becoming punctured or weakened in any way by abrasion on a rough surface (Plate 23). Each balloon is filled to give the required lift by tying weights to the brass connection at the end of the filling line where it fits into the neck of the balloon. The hydrogen is then passed into the balloon until sufficient lift has been acquired, to raise the weights clear of the ground. The filler is then taken off and the balloon-neck plugged with a light brass stopper which is held secure by means of a Jubilee clip. The appropriate length of rigging is then tied to the neck and used to tether the balloon to a heavy weight until required.

The arrangement of the rigging is seen in Fig. 23. Long lengths of good quality No. 1 gauge cotton string are used to keep the balloons well clear of



-Plate 24. -

Items used in the rigging. From left to right:-

Top row: double release mechanism, balloon plug,
jubilee clip and single release mechanism.

Bottom row: brass hoop for release mechanism,
ball-race, steel ring used in assembling the rigging
(see chapter 6.)

each other and to keep the angle of swing of the whole apparatus as small as possible. If the balloons were all bunched together, the bursting of one would be liable to cause the others to burst also. A parachute is incorporated as a safety precaution in case all the balloons do burst but, since this does not have much effect at the highest altitudes due to the low air resistance there, the initial rate of descent is high but decreases exponentially with height. The parachute is made of muslin and an area of about 10 sq. ft./Kgm. load is used as this gives a rate of descent of about 1000 ft./min. at the lower altitudes. The strings from the corners of the parachute are kept in position by securing them to an aluminium hoop of diameter 2 feet. The upward pull of the balloons is taken at the centre of the parachute where a wad of cotton waste is used to provide a convenient means of tethering. Release mechanisms are provided for the three balloons. These are seen in Plate 24 together with other items of the rigging. The balloon cords are fitted with brass loops which fit into grooves in the aluminium plates. When a balloon is pulling, the loop presses on the end of its groove but, if the balloon bursts and falls, it pulls its loop free. A steel wire spring is used to prevent the loop coming out accidentally in any buffetting which

may ensue if the apparatus passes through turbulent air. This release mechanism prevents the parachute from becoming entangled with the cord tied to a burst balloon or with the balloon fabric itself.

The cotton string is made up of many strands twisted together and when a length of it is in tension, there is a tendency to untwist. To keep the triangles as still as possible, cord is used for the lower lengths of rigging and, as a further precaution, the junction of the parachute to the top triangle is effected by means of a thrust ballrace (Plate 24) which leaves the triangle quite unaffected by any twisting of the supporting cord.

The apparent stability of the triangles as seen from the ground after release, was most reassuring and in marked contrast to the spinning and swaying of the apparatus in one of the test flights which did not contain the ballrace and triangles.

CHAPTER 4.

THE GROUND EQUIPMENT.

(a) Reception - (i) the 30 Mc./s. receiving equipment.

Two aerials already in existence were overhauled and used for the test flights with a 30 Mc./s. transmitter. One was a half-wavelength vertical dipole which was actually the top 19 feet 6 inches of a lightning conductor which ran to earth from the top of a 38 feet high flagpole on the tower of the Physics Department 80 feet above the ground. To bring the aerial into operation, this top section of the conductor was disconnected from its lead to earth, and coupled to an auto-transformer contained in a weather-proof box fixed to the flagpole. This transformer matched the impedance of the aerial (approximately 3,000 ohms) to an 80 ohm concentric cable which fed the signals to the receiver.

Since this aerial would not pick up the radiations from the vertical aerial of the transmitter when the latter was overhead, a second aerial was provided, this time a centre-fed, horizontal, half-wavelength dipole which was situated 29 feet ($3 \lambda/4$) above a flat

roof at a slightly lower level than the tower. Despite the transmission being vertically polarised this aerial gave good reception, possibly due to reflections from the many buildings nearby and from Arthur's Seat, an 822 feet high hill less than a mile away.

In order to preserve the sharpness of the timing pulses transmitted by the radio sonde, a receiver with a large bandwidth had to be employed. This was a modified ex-Air Ministry 'GEE' receiver, type R 1355 which had one R.F. stage, local oscillator and mixer followed by five stages of I.F. amplification at 7.7 Mc./s., a diode detector, video frequency amplifier and a cathode follower output stage.

This receiver was kindly supplied by Mr. I.M. Hunter who also made an elaborate filter circuit to discriminate between the timing pulses which were 50 to 100 secs. long, and interference pulses which are characteristically very short - of the order of a microsecond or two. Unfortunately this circuit was not wholly suitable since it utilised the trailing edge of the second timing pulse instead of the sharp leading edge. A much-simplified version of Mr. Hunter's circuit was used for two of the test flights and the circuit is shown in Fig. 24.

The first valve acted as a separator, the A.F.

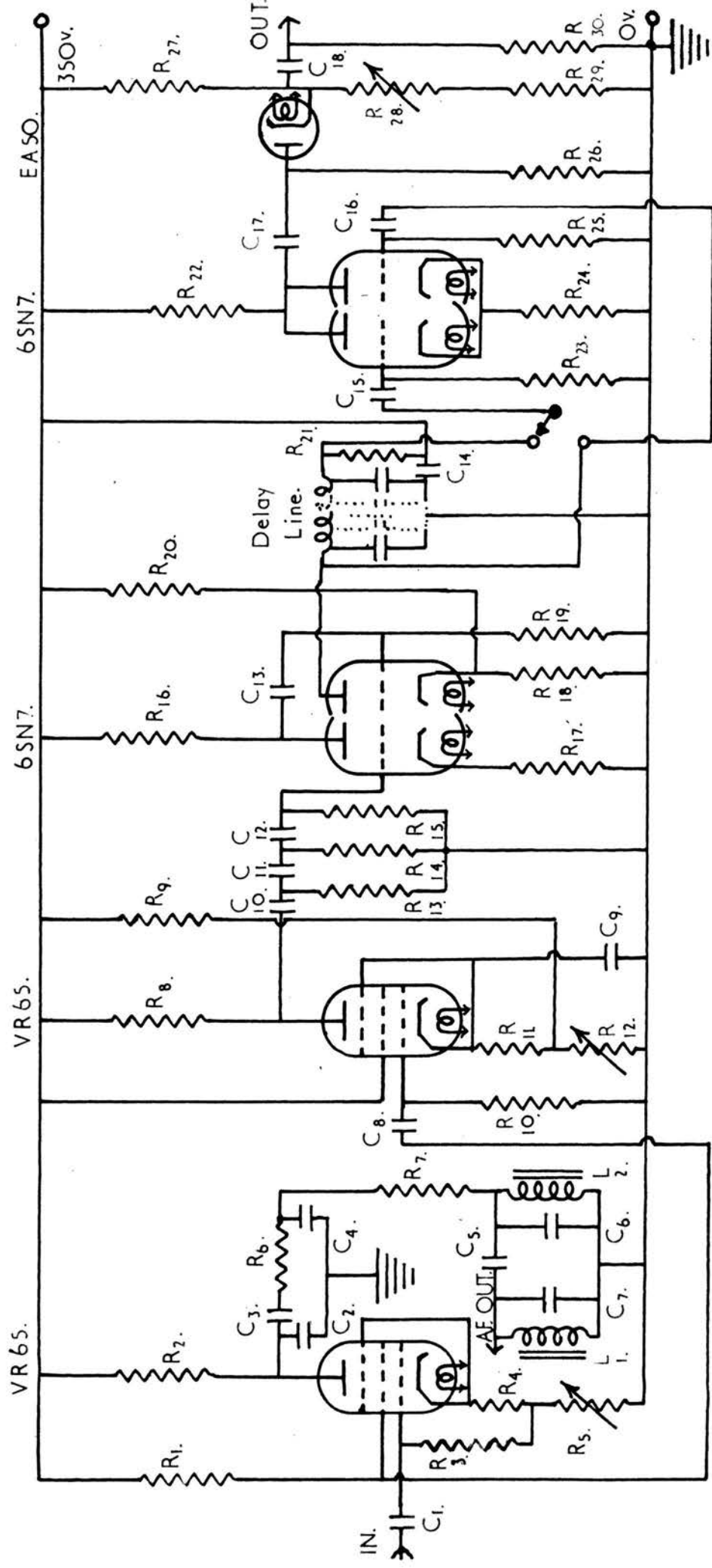


Fig. 24.

Circuit of First Filter Unit.

(Component list - page 153).

signal from the anode passing through a low-pass filter to an output plug while the measuring pulses were taken from the screen grid to a second valve which had a variable bias control. Hence this stage could be adjusted to amplify only the pulses, which were roughly three times the amplitude of the audio signal. A high-pass filter suppressed any audio frequencies still remaining and the pulses were then sharpened in the following stage. The next valve was a double-triode whose two sections were inter-connected in such a way that an appreciable output was obtained only when signals were on both grids simultaneously. With the selector switch in the position shown on the diagram it will be seen that, while the pulses were fed directly on to one grid, they had to pass through a delay line to reach the other grid. The delay produced was a few microseconds and so any pulses of this order of magnitude would not appear at the anode of the valve or, if they did, would be of smaller amplitude than the desired measuring pulses. A diode with a variable voltage on its cathode then acted as a discriminator.

When this circuit was accurately adjusted it did cut out very sharp interference pulses but the setting was very critical. It was unable to cope with the signals from the receiver when the signal to noise

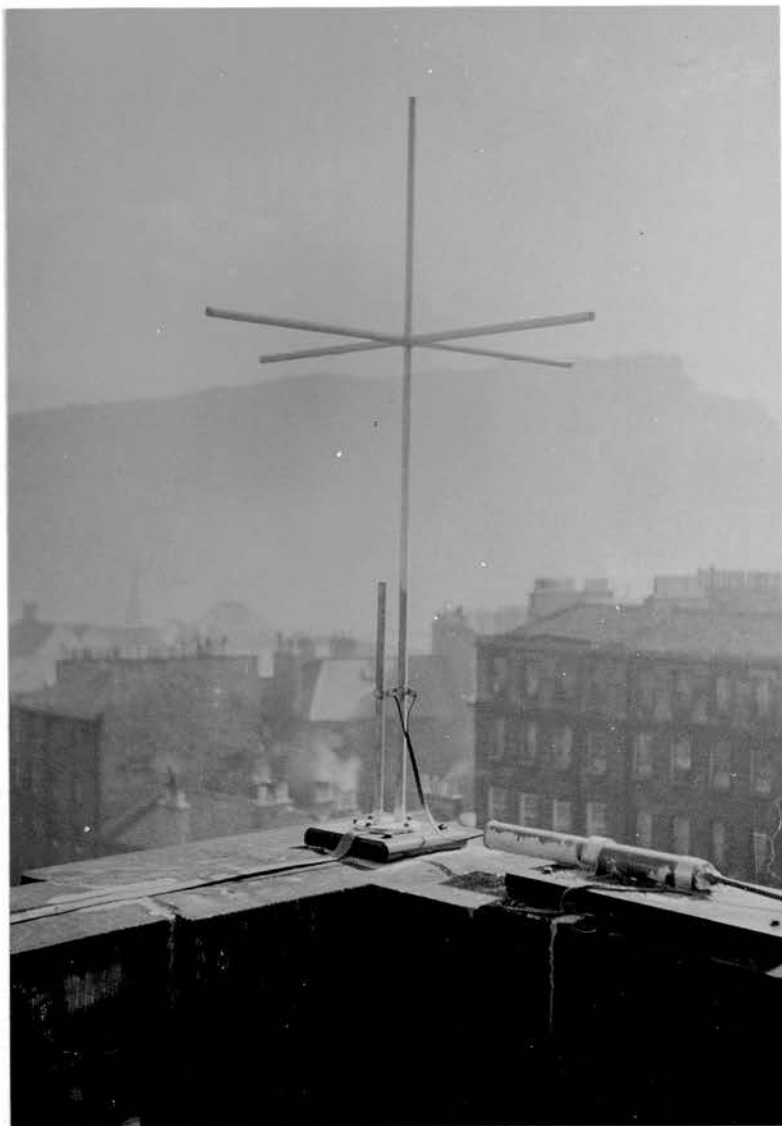
ratio became low. It was also upset by the 'mush' which appeared on the tops of the timing pulses since these momentarily suppressed the carrier wave completely.

(a) Reception - (ii) the 150 Mc./s. receiving equipment.

Two completely new aerials and their feeders had to be installed for the new transmitting frequency. They are roughly in the same positions as the two aerials described above, but are completely different in design.

The main aerial (Plate 25) consists of three, half-wavelength, tubular conductors mutually at right angles to each other in the manner of a set of co-ordinate axes which accounts for this type of aerial often being called an 'XYZ aerial'. The vertical section is supported by an additional quarter-wavelength of conductor alongside which is a quarter-wavelength matching stub.

The lead-in is of 80 ohm concentric cable (UR 18) which has an air-spaced polythene insulator of star cross-section between the 7-strand conductor and the copper screening, the latter being covered in a waterproof plastic sheath. The attenuation constant of this cable is 2.9 db. per 100 feet.



-Plate 25. -

The XYZ receiving aerial and the matching
device for the lead-in.

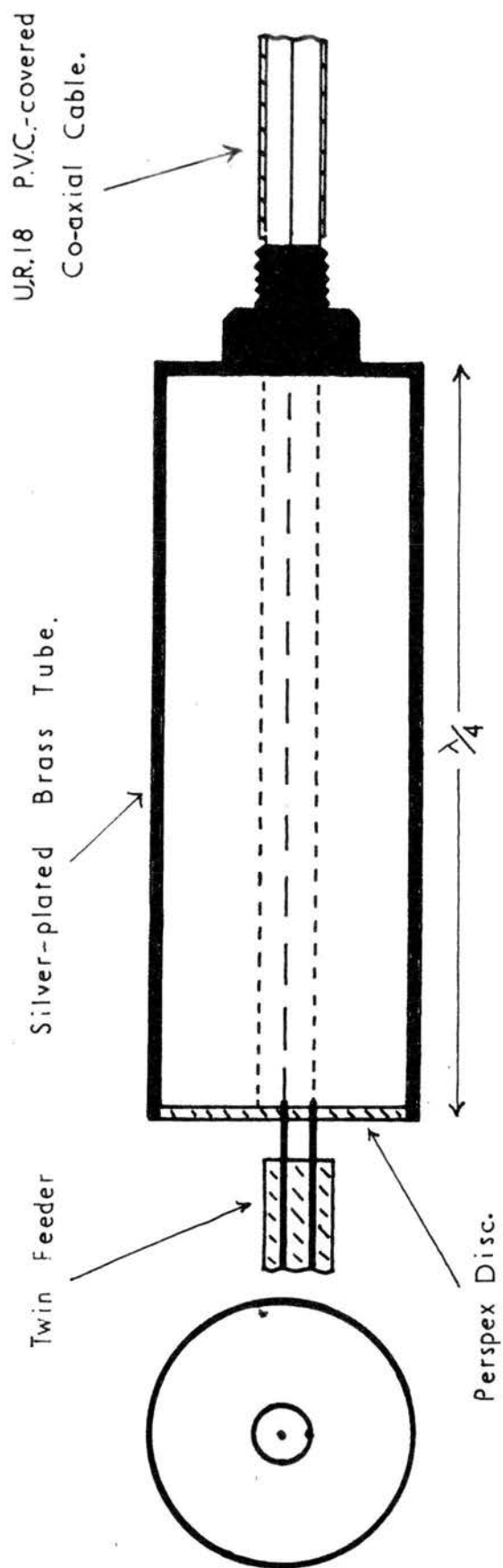


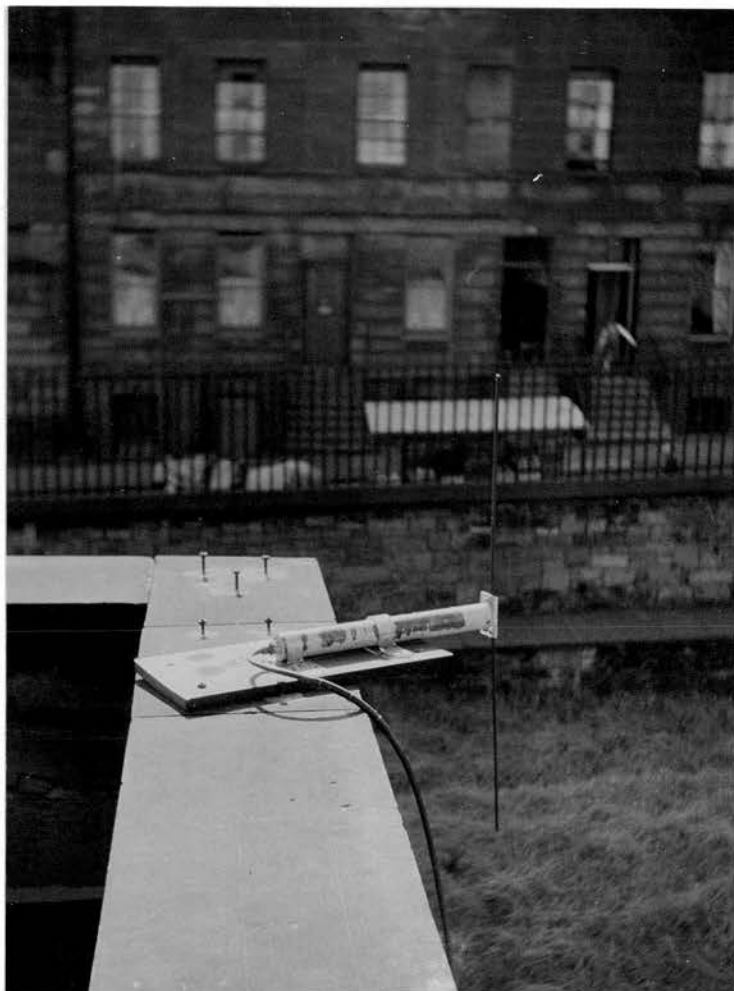
Fig. 25.

Diagram of a Balanced-to-Unbalanced Transformer
or "bazooka".

This lead-in was carefully matched to the aerial. Firstly the 80 ohm unbalanced feeder was matched to a short length of rubber covered 300 ohm twin feeder by means of a balanced-to-unbalanced transformer or 'bazooka'. This is shown diagrammatically in Fig. 25 and consists of a quarter-wavelength-long piece of hollow brass tubing up the centre of which passes the co-axial cable whose copper screening is in contact with one end of the tubing. The conductor and screening of the co-axial cable are soldered to two terminals of a socket embedded in a Perspex cup which fits into the other end of the tubing. The length of balanced feeder is furnished, at one end, with a plug fitting this socket and, at the other end, with two clamps which fit on to the quarter-wavelength matching stubs of the aerial. The aerial was matched to the feeder by adjusting the positions of these clamps.

Two positions were arranged for the XYZ aerial, one being up on the tower with a 225 feet long lead-in. In case the attenuation in this cable was too great, an alternative position was situated lower down with a 75 feet long lead-in.

The XYZ aerial is normally on the tower and a simple centre-fed, half-wavelength dipole is used as a reserve aerial in the second position (Plate 26). This aerial did not require matching but a second



-Plate 26. -

The alternative position for the main aerial
shown equipped with a simple dipole.

'bazooka' was fitted to the lead-in to facilitate the transference of the main aerial if necessary.

The XYZ aerial and the 'bazookas' are silver-plated to improve their H.F. current-carrying properties and this plating is protected from the weather by a coat of cellulose paint. All joints in the 'bazookas' are covered with wax to prevent moisture getting into the co-axial cable and ruining its insulation.

The matching of the main aerial to its lead-in was done by taking a transmitter a mile or so away and using it to generate a weak signal. The settings of the balanced feeder connections on the matching stubs were then adjusted for maximum signal strength in both positions of the aerial. These settings, which were practically the same for both aerial positions, were checked during the first test flight of a 150 Mc./s. transmitter.

The 150 Mc./s. receiver is in two parts. The first part is an ex-Air Ministry type R 3118 receiver whose tuning coils were re-wound to cover the 150 Mc./s. band. This unit has two R.F. stages with a local oscillator and mixer followed by six stages of I.F. amplification at 10 Mc./s. and a cathode follower. From this unit the 10 Mc./s. signal passes on to the

second part of the receiver where another frequency changer feeds into a further three stages of I.F. amplification at a frequency of 4.5 Mc./s. This I.F. strip has a bandwidth of 200 Kc./s. at $\frac{1}{2}$ db. down. Either F.M. or A.M. detection can be selected by means of a switch. The former is effected through the conventional limiter and discriminator stages and the latter utilises the grid detection of the discriminator stage which also provides bias for the A.G.C. line. The detected signal is passed to two stages of video frequency amplification. From there it goes to the output terminal and also to a power stage driving a small loudspeaker. The timing pulses appear at the output plug with amplitudes of about 20 volts.

With the very simple transmitter circuit producing both amplitude and frequency modulation, it was found that the power transmitted in the sidebands fell off with frequency. This tended to make the pulses slightly less sharp and, to counteract this, the V.F. amplifiers were designed to have a response which rose with frequency.

The signal to noise ratio was very much better with F.M. than it was with A.M. and so the former type of reception was used in the later ascents and gave signals which were vastly superior to any achieved

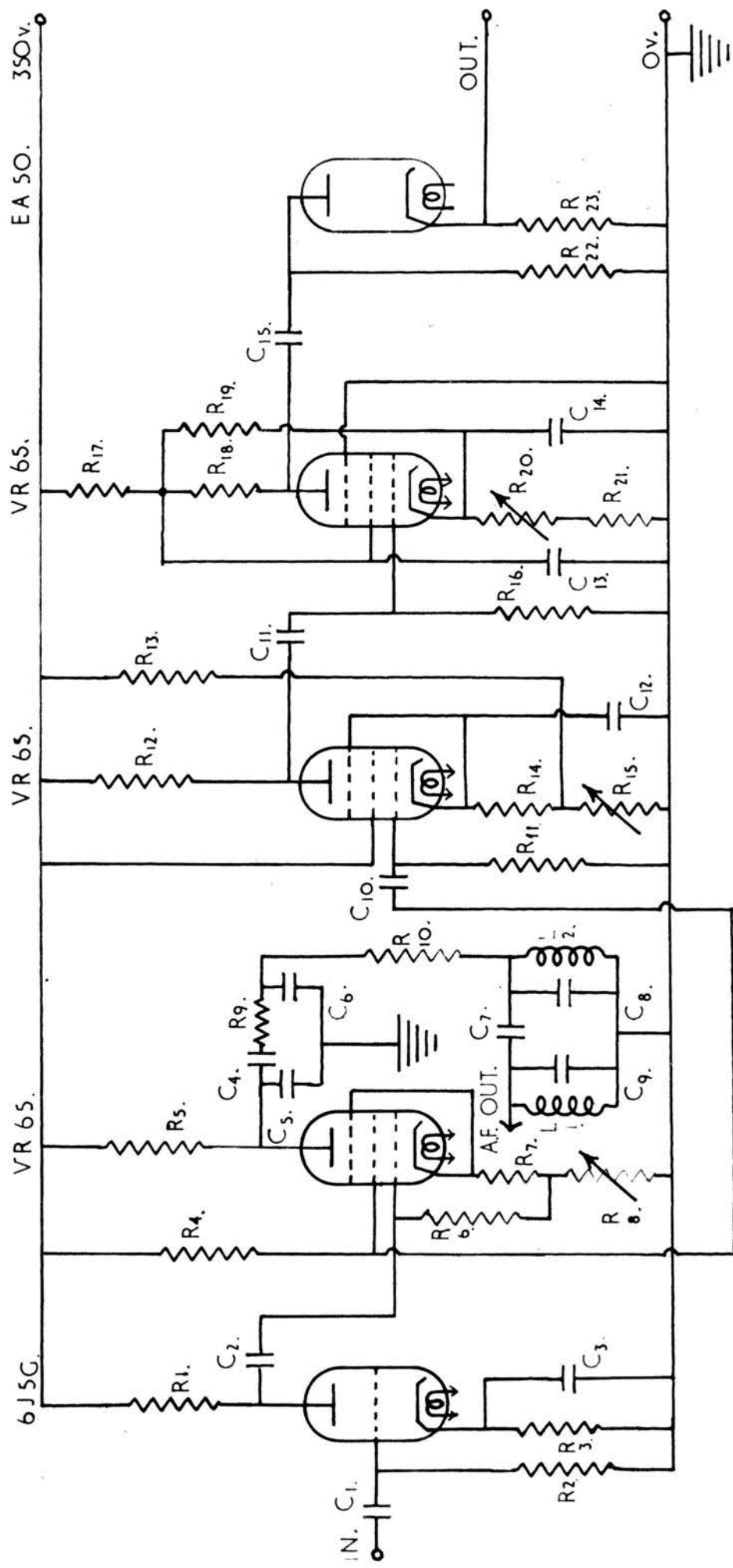


Fig. 26.

Circuit of Final Filter Unit.

(Component list - page 154).

with the 30 Mc./s. equipment. No change in accuracy was involved in the transition and the range of reception was much increased.

The signals from the receiver are passed to the filter circuit shown in Fig. 26 where the first stage is used merely to reverse the polarity of the pulses from the receiver so that they can be fed to the next two stages which separate out the A.F. oscillations from the measuring pulses exactly as in the circuit used with the 30 Mc./s. receiver. After this, the negative pulses pass on to the grid of a valve which is operated very near cut-off. In this way any noise or irregularity coming through on the tops of the pulses can be eliminated. These rough edges on the tops of the measuring pulses did occur with A.M. reception but not with F.M. reception where the carrier is present all the time.

This arrangement proved very satisfactory and passed very clean, uniform pulses on to the time-delay measuring circuit. Although both the minimum and maximum voltage levels defining the limits of the discriminating action, could be varied, practically no alteration of either was required during a flight.

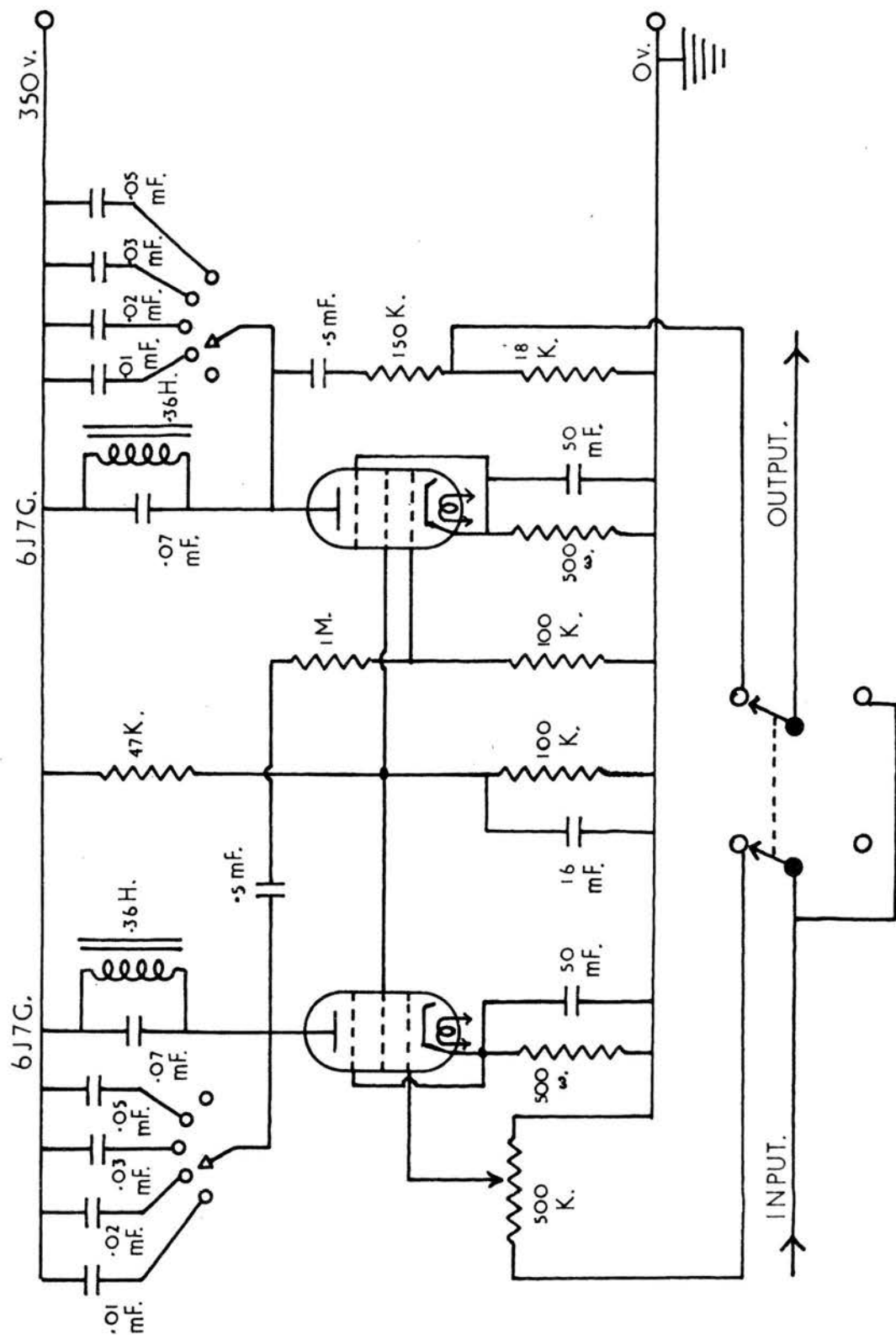


Fig. 27.

Circuit of Selective A.F. Amplifier.

(b) The Measurement of Audio Frequencies.

The audio signal from the filter unit is passed to a selective amplifier (Fig. 27) which has two stages whose tuned L.C. circuits have four pre-set positions covering the range 750 c./s. to 1000 c./s. with a bandwidth of 130 c./s. at half response. From here the A.F. signal is connected across one pair of plates of a C.R.O. while the output from a standard oscillator is put on the other pair. When the trace on the screen of the C.R.O. takes the form of a stationary loop, the frequency of the oscillator is the same as that of the A.F. signal.

The frequency standard is a Muirhead R.C. oscillator, specially designed for this type of work. Its scale can be read to 0.2 c./s. and its frequency is constant to that accuracy over the period of a flight, provided the oscillator has been switched on an hour or so before use in order to allow it to reach a constant temperature. The frequency of the oscillator at a few different settings was checked occasionally and was found to remain very constant.

(c) The Determination of Time-intervals between
Pairs of Measuring Pulses.

To measure the time delays between the pairs of measuring pulses, it is arranged that, during these

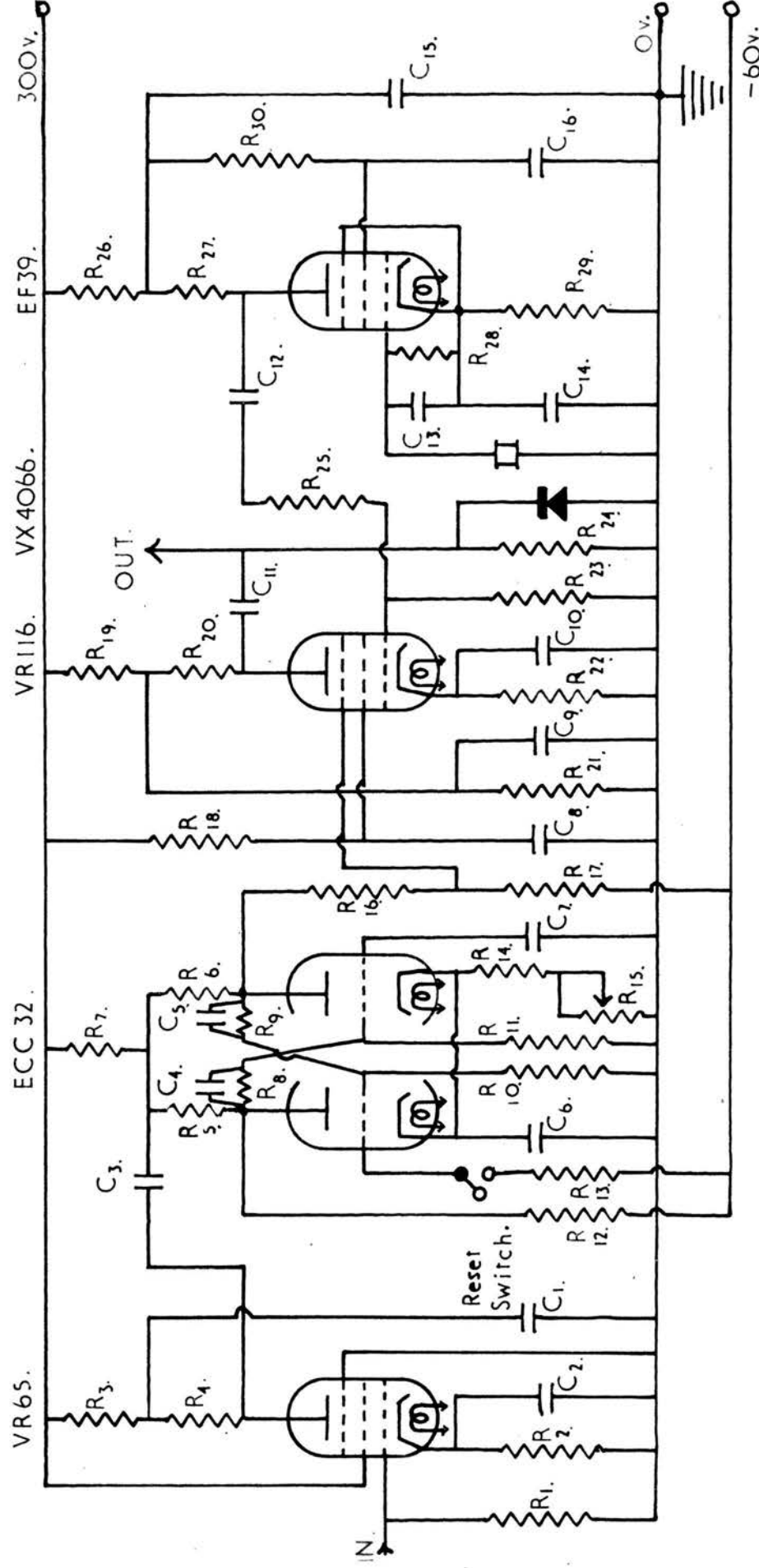


Fig. 28.

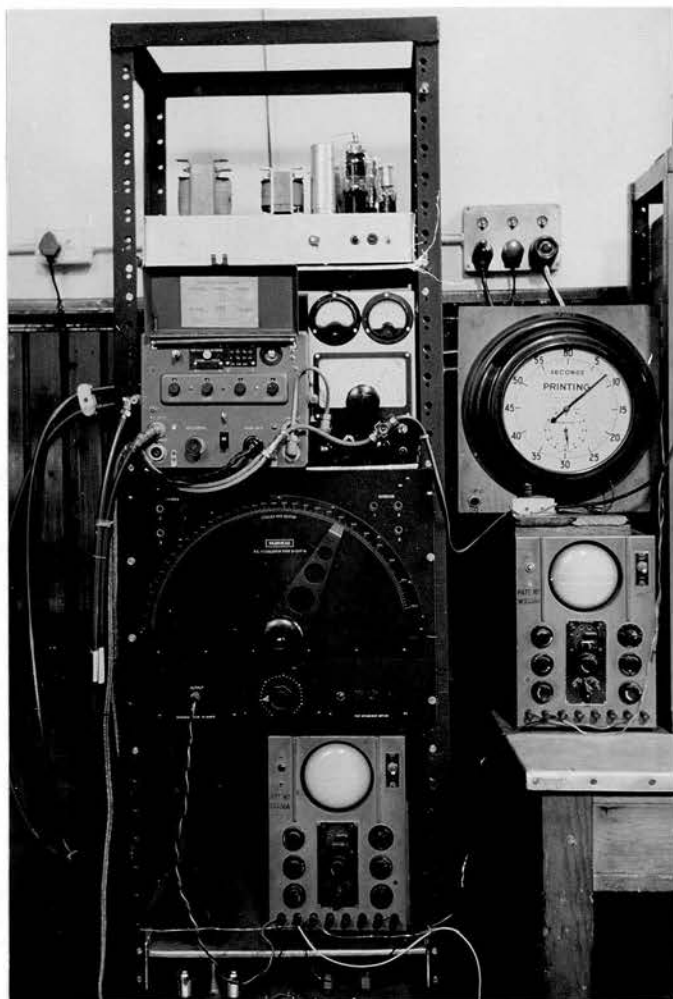
Circuit of 'Gated' Crystal Oscillator.

(Component list - page 155).

delays, the output from a 50 Kc./s. oscillator is passed into an electronic scaler where the oscillations are counted. The bursts of oscillations are produced by the circuit shown in Fig. 28.

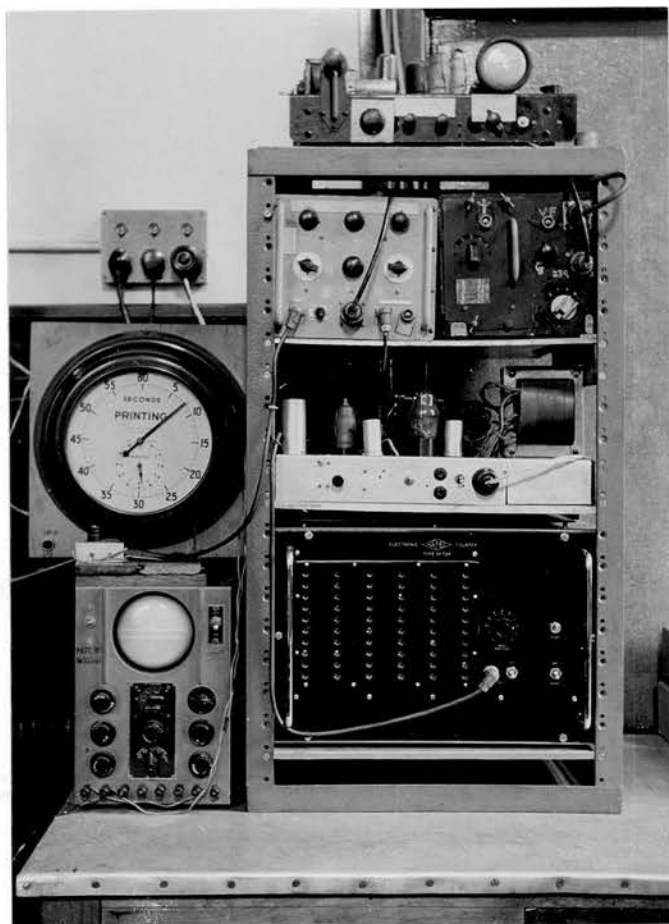
The timing pulses are amplified by the first valve into extremely sharp negative pulses which are used to trigger the second stage which is a multi-vibrator with two stable states. This stage produces positive steps in voltage whose lengths are equal to the time intervals between the pairs of pulses. These steps are used to 'gate' the VR 116 which has good suppressor control. The output from a 50 Kc./s. crystal-controlled oscillator is put on the control grid of the same valve and it is arranged that the oscillations only appear at the anode when there is a positive signal on the suppressor, i.e. during the intervals between the measuring pulses. The crystal is a type 5X unit made by the Quartz Crystal Co. and has a temperature coefficient of the order of 2×10^{-6} per $^{\circ}\text{C}$. and the frequency of the oscillator circuit is stable to better than 0.01%. An Airmec type 704 electronic scaler is used to count the oscillations.

The ground equipment is seen in Plates 27 and 28. The C.R.O. beside the scaler is used as a monitor and can be coupled to any one of five points in the filter circuits by means of a selector switch. The large



-Plate 27. -

One part of the ground equipment. From top to bottom of the main rack there is the receiver power-pack, the double "super-het." receiver, and the standard oscillator, C. R. O. and selective amplifier for measuring the audio frequencies.



-Plate 28. -

The other part of the ground equipment. On the rack there is a double-pulse generator equipped with its own monitor and used for test purposes; the filter unit and 30Mc/s. receiver; the gated crystal oscillator; the electronic scaler. To the left is the C.R.O. monitor surmounted by the master clock.

clock on top of the C.R.O. is conveniently situated between the A.F. part and the pulse section of the equipment.

(d) Procedure during Reception.

At least two people are required to record the data on the ground during a flight and it is best to have three, one measuring and recording the values of the audio frequencies relating to pressure and temperature, another operating the scaler and calling out totals to the third who tabulates them. Before the operations on the ground are described with reference to the sequence of events in the airborne equipment, it is necessary to summarise the working of the ozone radio sonde.

The lamp is flashing roughly twice every second and each time it flashes an intensity measurement is made and this intelligence sent to the ground in terms of a time delay between two pulses. The intensity measured refers to one of two light paths and these paths are selected alternately by a rotating sector. Coupled to the same mechanism as the sector, a switch connects the pressure and temperature elements alternately into the A.F. oscillator circuit. Thus the cycle of events is as follows.

(i) AIR. The temperature element is in use and the sector has selected the short path from lamp to photocell.

GROUND. The temperature frequency is measured and noted down together with the time. The bursts of oscillations from five pairs of timing pulses are allowed to register in the scaler before the latter is switched off and the total recorded together with the time. The scaler is then re-set and another total for five pairs of pulses allowed to accumulate. Usually three or four such totals are obtainable before the path changes.

(ii) AIR. The meteorological switch is changing from pressure to temperature and, in this intermediate position, both inductors are connected in circuit. The sector has moved slowly round and the short path is giving way to the long path. A shorting switch is preventing the signals from the lamp from actuating the comparator.

GROUND. No pressure or temperature readings are possible and no timing pulses are received.

(iii) AIR. The temperature element has been disconnected leaving the pressure element by itself in the circuit. Light from the long path is reaching the photocell and the comparator is able to function again.

GROUND. The pressure frequency is noted against time and the total numbers of counts for sets of five pairs of pulses are recorded together with the time.

(iv) Another transitional period leading back to the state of affairs described in (i).

The complete cycle takes approximately one minute during which the apparatus ascends about 1,000 feet.

CHAPTER 5.

THE CALIBRATION AND ACCURACY OF THE TELEMETERING SYSTEM.

(a) Pressure and Temperature.

The calibrations of the pressure and temperature elements are carried out using a special chamber which can be evacuated to a pressure of about 5 mm. Hg. and whose temperature can be controlled by heating or cooling trichlorethylene contained in an insulated jacket surrounding the chamber. To heat the liquid, electrical heating elements situated in the jacket are used and, for cooling, a quantity of solid carbon dioxide, in the form of small lumps, is mixed with the trichlorethylene. A motor-driven impeller keeps the jacket at a uniform temperature throughout and a fan inside the chamber helps to prevent temperature gradients forming there. An accurate mercury-in-glass manometer is connected to the chamber and enables the inside pressure to be measured with a precision of better than 0.2 mm. Temperature measurements are made with a thermocouple and microammeter, one junction being inside the chamber as near as possible to the elements, and the other outside in a flask of melting ice.

Calibration is carried out with conditions as nearly as possible the same as those which prevail

during a flight. Fly-leads passing through a vacuum-tight joint have to be used to connect the elements situated in the chamber to the radio sonde which is placed as near as possible outside. At the end of the calibration, the frequency of the pressure signal, with the element in the chamber, is compared with that when the element is replaced in the radio sonde. No change in frequency has ever been found and it is concluded that the comparatively long leads required during calibration, introduce no error. The same H.T. batteries and accumulators, fresh to begin with, are used throughout the calibration and hence an indication of the stability of the oscillator is obtained.

In the calibration of the pressure unit, the chamber is evacuated in a number of steps at a temperature of around 15°C . and the frequency of the A.F. signal corresponding to each pressure is noted. Before each reading is made it has to be ensured that the pressure in the chamber is constant. Slight leaks are inevitable in such a large system and, to obtain constant pressures, it is arranged that pumping can take place through a needle-valve and so compensate for the leaks. The manometer reading is corrected for temperature effects and a small zero-error, and is then converted to millibars and a master calibration curve

drawn relating audio frequency and pressure in millibars for the appropriate temperature.

The pressure unit is then re-calibrated at temperatures of about $+55^{\circ}\text{C}$. and -35°C . Since it is known that, for a given pressure, the variation of frequency with temperature is almost linear (Dymond, 1947), this furnishes information from which temperature correction curves may be drawn for the unit.

The temperature unit is calibrated over a range of roughly -30°C . to $+55^{\circ}\text{C}$., a sufficient time being allowed between each reading to allow the chamber to reach thermal equilibrium. The temperature calibration curve is drawn on the same graph as the pressure calibration and the correction curves. Fig. 29 shows a much-reduced version of a typical chart. In this case the sensitivity of the pressure element is 7.9 mbs./cycle at the high pressures and 3.8 mbs./cycle at the low ones. The mean slope of the temperature graph is $0.8^{\circ}\text{C}/\text{cycle}$. The maximum temperature correction that would have to be made for a rise of 10°C . is -1 c./s. at the higher frequencies.

Before a flight, observations are made of the atmospheric pressure and of the temperature inside the radio sonde near the temperature element. The corresponding frequencies are read off the calibration chart and compared with the frequencies actually

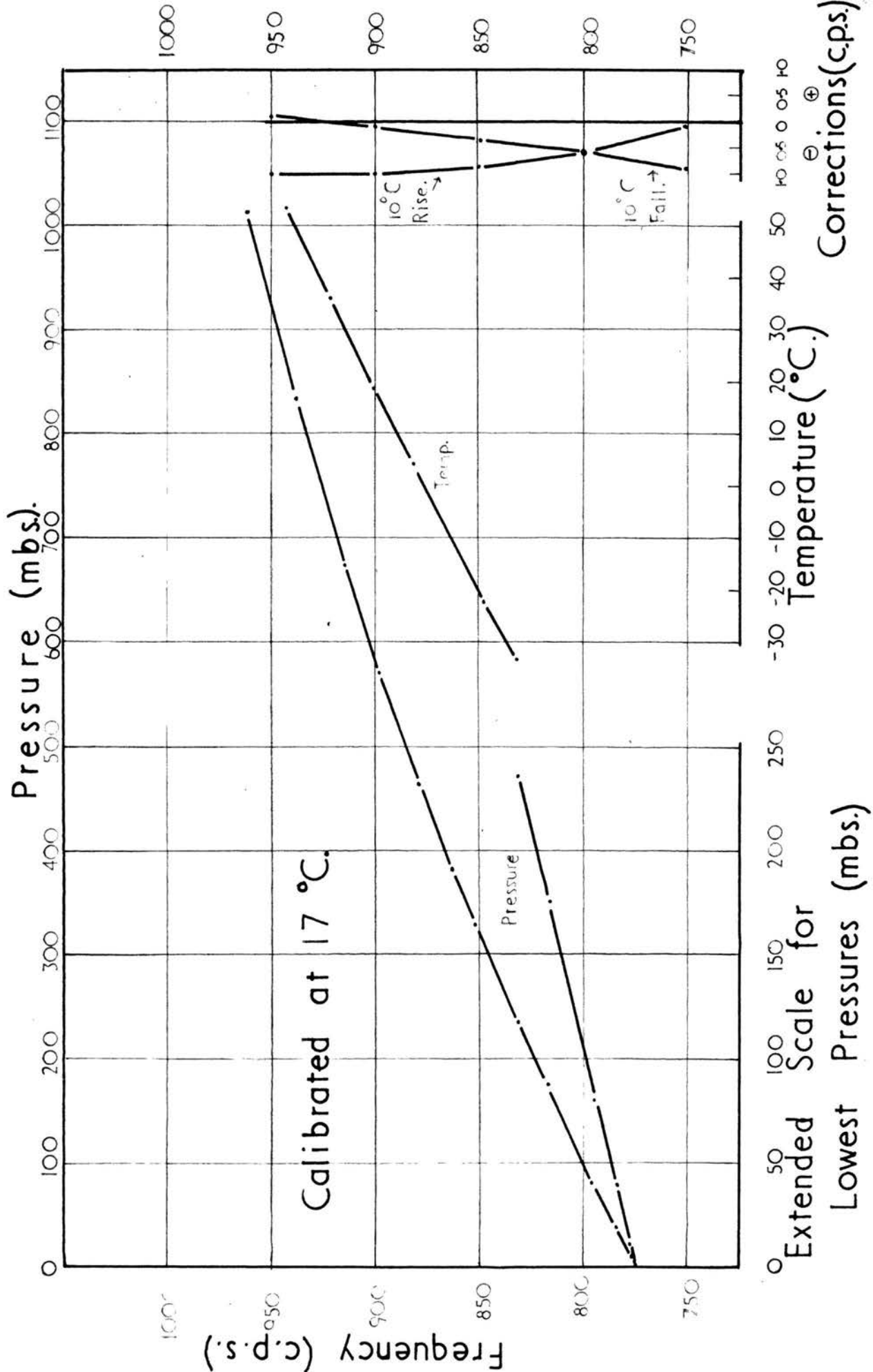


Fig. 29. Calibration Chart (much reduced in scale).

transmitted by the instrument. There are usually slight differences due to the battery voltages not being quite the same as those at the time of calibration. Also secular changes may occur in the meteorological elements including ageing effects and mechanical shock. The overall change in frequency due to these causes is around 0.5 c./s. for the pressure unit. A constant correction, called the control correction, is applied to the calibrations. This procedure is rather arbitrary but, on one occasion when a pressure element was re-calibrated after a flight, it was found that its two calibration curves lay very nearly parallel to each other, thus showing the correction to be almost independent of pressure. The error introduced by this approximation is made small by taking precautions to keep the control correction itself small.

To obtain a pressure-time graph for a flight, the first step is to produce a temperature-time graph by applying the temperature control correction to the frequencies measured during the flight and then referring to the calibration chart. The transmitted pressure frequencies are then corrected for the effect of temperature and then the pressure control correction is applied to them. The pressures corresponding to these frequencies can now be read off the chart

and plotted against time.

To convert the pressure-time graph to a height-time one, the height intervals between different pressure levels in the atmosphere have to be calculated. This is most conveniently done using a Meteorological Office Radio Sounding Chart (Form 2813). On this form are plotted data obtained during a routine radio sonde flight from the local weather station at Leuchars. Figures are taken from the flight occurring nearest to the time of the ozone flight and these give the variation of temperature with pressure in the atmosphere in the range 1000 mbs. to 80 mbs. This information is plotted on the Sounding Chart from which the height intervals can be determined. Heights above the 80 mb. level are interpolated on the assumption that, thereafter, the atmosphere is at constant temperature.

In an examination of the errors in pressure measurement with the Kew radio sonde, Dymond (1947) concluded that casual errors produced an uncertainty of up to ± 5 mbs. and systematic errors an uncertainty not greater than ± 2 mbs.

The casual errors are mainly due to the pressure units not having individual temperature correction curves drawn for them. A standard correction curve is used for them all but there are bound to be slight

differences between the units. In the ozone sonde each pressure unit has its own correction curve and also is contained in a thermally-insulating container. Thus, in contrast to the Kew radio sonde where the pressure unit is subject to very large changes of temperature, the interior of the ozone apparatus varies very little in temperature during the ascent. As a result, it is estimated that casual errors affect the measurement of pressure by, at the most, $\pm \frac{1}{2}$ mb. at any pressure.

There are several sources of systematic error, one of which has already been mentioned, namely the assumption that the control correction is the same for all pressures. In the Kew radio sonde control corrections of up to ± 5 c./s. are tolerated but, in this series of flights, an average value of ± 0.5 c./s. was obtained. This improvement is partly due to the fact that the calibration and flight are made with the element connected to the same oscillator and in conjunction with the same frequency standard which is kept checked. Other helping factors are the relatively short time between calibration and flight and the careful avoidance of mechanical shocks or stresses. Also, since the temperature variation inside the container is small, any time lag for the pressure unit to reach the temperature of its surroundings is

not so important. Thus the systematic errors in the pressure measurement of the ozone sonde must be equivalent to about ± 0.5 c./s. which means less than ± 2 mbs. at low pressures and less than ± 4 mbs. near the ground.

It is estimated that the temperature unit can measure the temperature inside the container to an accuracy of $\pm 2^{\circ}\text{C}$. This is sufficiently accurate for the requirements of the temperature correction curves for the pressure unit.

Thus the accuracy in pressure measurement is better than ± 2.5 mbs. in the most important range below about 100 mb. In terms of height, taking the uncertainties of atmospheric temperature into account, the error could be $\pm 2,500$ ft. at 75,000 ft. and almost three times this at 100,000 ft. If greater accuracy were required, especially at the higher altitudes, a double aneroid capsule could be used in the pressure unit instead of the single one. A phosphor-bronze double capsule made by Kelvin, Bottomley and Baird is shown in Plate 29 beside a normal capsule installed in its inductor unit. It consists of a main capsule of slightly lower sensitivity than the steel one, in series with a second capsule which remains collapsed until a pressure of about 150 mbs. With this type of element it has been

estimated that pressures lower than 150 mbs. can be measured with an accuracy of ± 1 mb. (Pullar and Dymond, 1953). At an altitude of 75,000 ft. (22.6 Km.) this means an uncertainty of $\pm 1,000$ ft. (0.3 Km).



-Plate 29. -

**A double aneroid capsule beside a pressure unit
equipped with the normal single capsule.**

(b) Ozone measurement - (i) the relation between ozone content and the output of the photocell amplifier.

- Let I_0 = the intensity of the light of wavelength 2537 A produced by the lamp.
- I_s = the intensity of this light at the photocell after it has travelled along the short path.
- V_s = the amplitude of the corresponding pulse from the photocell amplifier.
- I_L = the intensity of the 2537A light at the photocell after it has travelled along the long path.
- V_L = the amplitude of the corresponding voltage pulse from the photocell amplifier.
- a = the absorption coefficient of ozone for 2537 A light.
- d = the amount of ozone in cm. at S.T.P. contained in the ten metre path.

Then $V_s \propto I_s \propto I_0$ for the short path which is too small for absorption to cause any measurable effect. For the long path, however, $V_L \propto I_L \propto I_0 \times 10^{-ad}$ and combining this with the previous expression gives

or
$$d = \frac{1}{a} \log_{10} \frac{V_s}{V_L} + \text{constant.}$$

At ground level this equation is

$$d_g = \frac{1}{a} \log_{10} \left[\frac{V_s}{V_L} \right]_g + \text{same constant.}$$

$$\therefore d - d_g = \frac{1}{a} \log_{10} \frac{V_s}{V_L} - \frac{1}{a} \log_{10} \left[\frac{V_s}{V_L} \right]_g$$

If it is arranged that $V_s = V_L$ on the ground, this expression becomes

$$d - d_g = \frac{1}{a} \log_{10} \frac{V_s}{V_L}$$

and since flights are undertaken on very still mornings from the centre of a city it can be assumed that

$d_g = 0$ (Ehmert, 1952). Thus the ozone content, ϵ cm $[O_3]$ at S.T.P. per Km. of air, is given by

$$\underline{\underline{\epsilon = 100 d = \frac{100}{a} \log_{10} \frac{V_s}{V_L}}}$$

From this relation the variation in the ratio

V_s/V_L to be expected during a flight can be deduced.

It must be remembered, however, that in practice, neither V_s nor V_L is produced entirely by light of wavelength 2537 Å. In Chapter 3(a) it was shown that 94% of V_s and 83% of V_L were related to 2537 Å light, the remainder being mainly due to 3126 Å light. The light of this latter wavelength will not

show absorption in the ten metre path and so it can be assumed that

$$V_L = V_{2537} + V_{\text{constant}}$$

On the ground, $\epsilon = 0$ and $(I_G)_{2537} \propto (I_{\text{LAMP}})_{2537}$

At the ozone maximum, $\epsilon = 0.02 \text{ cm} [0.3] / \text{Km.}$ and

$$(I_{\text{MAX}})_{2537} \propto (I_{\text{LAMP}})_{2537} \times 10^{-140 \times 0.0002}$$

$$\therefore \left(\frac{I_G}{I_{\text{MAX}}} \right)_{2537} = 10^{140 \times 0.0002} = 0.94 \quad \text{which}$$

means that there is a 6% change in I_{2537} and also in V_{2537} .

Thus, of 100 parts of V_L , 83 are subject to a variation of 6% and 17 are constant. Thus the variation in V_L is 5%. Since V_s should be constant or, if slightly varying, then accompanied by a corresponding variation in V_L , it is concluded that the ratio V_s/V_L will change by about 5% during a flight. If V_s and V_L are both 30 volts on the ground and V_s remains constant throughout the flight, this means that V_L will change by 1.5 volts. Allowance may have to be made for the effect of temperature on the absorption coefficient, α , but this quantity is independent of pressure (Vassy, 1937; Vassy and Mahmoudian, 1952).

- (ii) The relation between the output voltages of the photocell amplifier and the time delays measured in terms of counts at 50 Kc./s.

Over the whole working range of the telemeter there was found to be a very linear relation between voltage and resultant time delay, i.e. between volts and counts. Thus the characteristic of the Miller run-down can be represented by a straight line of slope S counts per volt.

Let a known voltage, V , produce a number of counts C . Then any number of counts, c , can be related to a voltage, v , by the equation

$$(V - v)S = c - C$$

which holds

for $V \gg v$ and so for $C \gg c$.

$$\therefore v = V - \frac{c - C}{S}$$

Thus the ratio V_s/V_L becomes
$$\frac{V - \frac{c_s - C}{S}}{V - \frac{c_L - C}{S}}$$

where c_s and c_L are the counts relating to the voltages V_s and V_L respectively.

$$\therefore \frac{V_s}{V_L} = \frac{(VS + C) - c_s}{(VS + C) - c_L} = \frac{K - c_s}{K - c_L}$$

where $k = (\nabla s + c)$ is a characteristic of the Miller run-down.

(iii) The accuracy of the voltage-counts transition.

A steady voltage was applied to the reference condenser of the comparator and readings taken of the total numbers of counts for ten pairs of timing pulses. One hundred such totals were recorded and their values are shown in the following table. (See page 103a).

Mean value = 3800.45 counts

Sum of the squares of the deviations from this mean

= 3416.2

∴ Probable error in any single value

$$= \frac{2}{3} \sqrt{\frac{3416.2}{99}}$$

= 4 counts.

Thus the accuracy of any one observation in the above table, 3798 say, is:-

Counts for 10 pairs of measuring pulses

= 3798 ± 4

∴ " " 1 pair " measuring pulses

= 379.8 ± 0.4

3800	3811	3816	3813	3805	3803	3800	3796	3801	3801
3803	3782	3811	3796	3803	3794	3802	3800	3804	3800
3798	3783	3787	3803	3804	3805	3797	3798	3801	3804
3799	3785	3803	3801	3798	3798	3797	3799	3800	3800
3802	3783	3815	3798	3802	3806	3800	3805	3804	3802
3802	3790	3803	3802	3800	3793	3793	3798	3804	3800
3799	3800	3806	3804	3800	3801	3800	3810	3804	3800
3795	3813	3798	3803	3802	3800	3801	3800	3801	3801
3799	3798	3800	3805	3800	3805	3797	3800	3799	3798
3790	3802	3807	3798	3797	3806	3799	3801	3800	3803

To find what this last figure meant in terms of voltage, the run-down of the Miller time-base was calibrated.

Reference Voltage applied to Comparator	Mean value of counts for 1 pair of pulses
40.6 volts	139.9 counts
37.7	252.8
35.2	349.9
33.0	435.4
30.0	543.2
28.2	617.1
25.8	708.8
24.0	787.3
21.8	942.0

Using this information it is found that the value 379.8 ± 0.4 counts corresponds to a voltage of $34.34 \pm .01$ volts applied to the comparator.

(iv) The effect of variations in the H.T. voltage supply.

The effect on the accuracy of the comparator of variations in the H.T. supply must be considered. The comparator was re-calibrated at two other settings of the H.T. voltage. In all three calibrations the reference voltages were obtained from a potentiometer across the H.T. supply. The results are tabulated below^{*} (see also Figure 30) and show that the counts for a certain setting of the potentiometer are almost independent of the value of the H.T. voltage.

This means that if any variation in the H.T. voltage of the comparator is accompanied by a proportional change in the reference voltage, the counts will be invariant. Since, in the ozone sonde, the 120 volt supply for the amplifier and the 48 volt supply for the comparator are taken from the same battery, there will be a certain amount of self-compensation but this will not be completely effective.

However it is the ratio V_s/V_L which has to be measured and the value of this will not change due to small variations in the H.T. supply of the amplifier. Thus the counts read off on the ground

* See page 105.

Potr. Setting	Reference voltage			Mean counts for 1 pair pulses		
	H.T. 51	H.T. 48	H.T. 45	H.T. 51	H.T. 48	H.T. 45
1.	43.1	40.6	38.1	140.2	139.9	140.5
2.	40.1	37.7	35.4	251.9	252.8	252.9
3.	37.4	35.2	33.0	348.6	349.9	350.4
4.	35.1	33.0	31.0	434.3	435.4	436.5
5.	31.9	30.0	28.1	541.9	543.2	544.6
6.	29.9	28.2	26.4	615.5	617.1	618.6
7.	27.5	25.8	24.2	706.5	708.8	712.1
8.	25.5	24.0	22.5	782.6	787.3	796.6
9.	23.2	21.8	20.5	894.4	942.0	-

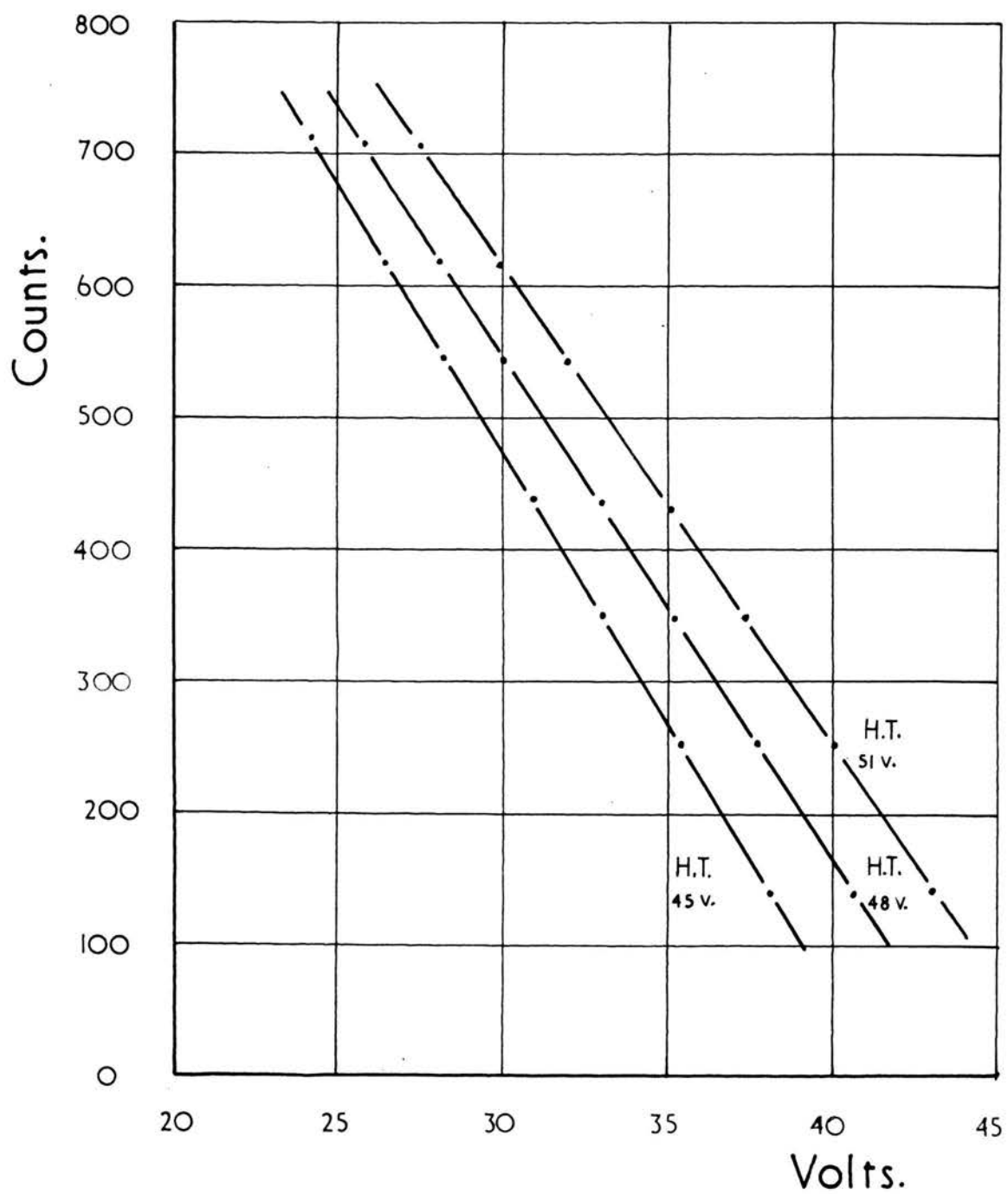


Fig. 30.

Characteristics of Miller Time-Base.

corresponding to the two voltages, will accurately give the ratio V_s/V_L if the correct value is known for the constant K in the relation. $\frac{V_s}{V_L} = \frac{K - c_s}{K - c_L}$.

The variation of K for different values of the comparator H.T. voltage was studied, using data from the above calibrations.

H.T. voltage	S counts/volt	V volts	c counts	K $=(VS + c)$
51	36.8	30	614	1718
48	38.8	30	548	1712
45	41.4	30	478	1720

Thus for a change of 6 volts in the comparator H.T. supply, the value of K changes by an insignificant amount. From chapter 3(c) it is known what the magnitudes of the H.T. supply variations are likely to be during a flight. The relevant figures are reproduced below.

Supply	Voltage drop	
	After 2 hours	After 3 hours
Amplifier	1.3 volts	2.1 volts
Comparator	0.7 volts	1.6 volts

Thus the range of H.T. voltage occurring in a flight is much smaller than that over which the comparator should be capable of measuring a voltage ratio accurately.

This conclusion was checked by a test under actual working conditions. With a certain position of the slit, the light from the short path was allowed to reach the photocell and intensity measurements were made through the complete telemetering system with different H.T. voltages on the amplifier and comparator. The position of the slit was then altered to give a second light intensity and the whole process repeated. The results were:-

Amplifier H.T.	120 volts	118 volts	118 volts
Comparator H.T.	48 volts	48 volts	46.9 volts
C_1 Counts relating to first light intensity	504 ± 2	528 ± 2	481 ± 2
C_2 Counts relating to second light intensity	753 ± 2	775 ± 2	731 ± 2
Ratio $\frac{K - C_1}{K - C_2}$	$1.210 \pm .004$	$1.212 \pm .004$	$1.207 \pm .004$

It is seen that the three ratios are equal within the limits of accuracy.

(v) The effects of L.T. supply variations.

The variations expected in the relevant L.T. supplies during a flight are given in the following table;

Supply	Voltage drop	
	after 2 hours	after 3 hours
Amplifier fils.	0.2 volts	0.4 volts
Comparator "	0	0

Tests with the amplifier showed a very slight decrease of around 5 counts when the 6.3 volt heater supply dropped by 0.4 volts.

The comparator is also very slightly affected by variation of its L.T. voltages, a drop of 0.1 volts in 1.4 volts causing an increase of 5 counts in the time delay between the measuring pulses. This is in the opposite direction to the effect of a drop in the amplifier L.T. voltage.

High stability components are used for the critical components of the comparator and, since there is efficient thermal insulation, no temperature effects need be taken into account. It is therefore concluded that the ratio of two voltages applied to the comparator can be measured at any time during a flight with an accuracy of around 0.2%.

(vi) Variations in the signals to the comparator.

Besides those allowed for in the above figures, there are other inaccuracies due to noise in the amplifier fluctuations in lamp intensity and other factors influencing the amplitude of the voltage signals applied to the comparator. These are now considered.

Due to the large grid resistance of the first

stage of the photocell amplifier, there is some thermal noise produced. This is amplified together with the noise from other, less troublesome, sources and appears at the output as a signal of magnitude

0.05 volts r.m.s. for minimum gain }
0.6 volts r.m.s. for maximum gain. }

The effect of this noise was studied in conjunction with the effect of fluctuations of light intensity produced by the lamp. The following results^{*} were obtained for the counts relating to the light intensity over the long path in tests performed under actual working conditions. The radio sonde was attached to its triangle which hung freely from the top triangle carrying the mirrors.

Each figure in the last row of the above table refers to the probable error in the counts for one pair of timing pulses as deduced from any one total number of counts for five pairs of timing pulses. In a flight the mean value for several totals can be taken for a certain height interval, thus improving the accuracy. The slight drift over the five columns in the values of the mean counts for five pairs of pulses, is due to battery run-down. Dry batteries were used for the test and these are not designed to supply large H.T. currents.

* See page 111.

Total counts for 5 pairs of measuring pulses	2736	2741	2766	2798	2778
	2725	2762	2758	2794	2769
	2724	2723	2748	2772	2752
	2699	2744	2751	2760	2739
	2708	2724	2743	2778	2760
	2711	2739	2733	2764	2784
	2706	2706	2741	2754	2792
	2701	2703	2731	2754	2765
	2709	2731	2762	2749	2781
	2703	2744	2758	2755	2783
Mean value for 5 pairs of pulses	2711.8	2731.7	2749.1	2767.8	2770.3
Probable error in <u>any</u> <u>one</u> of the above totals for 5 pairs of pulses	± 8.1	± 12.1	± 8.0	± 10.9	± 11.5
.. Probable error in counts for 1 pair of pulses	± 1.6	± 2.4	± 1.6	± 2.2	± 2.3

The output of the lamp was found to be slightly dependent on its rate of flashing. The effect was small (around 5 counts) over a range of P.R.F.^s of 1 per sec. to 2 per sec., but for slower rates a larger difference was observed, amounting to 50 counts when the P.R.F. was lowered to 0.7 per sec.

A fluctuation in filament voltage of the lamp affects the intensity output, in that it slightly alters the P.R.F. of the lamp. The lamp filament is run off its own battery which should not vary in voltage during the period of a flight.

During the development of the lamp, no appreciable intensity variation was found when the lamp was gently heated. During an ascent the temperature of the lamp should not vary by more than 10° C.

Throughout the intensity measurements detailed above, the background illumination was constant. Thus the accuracy of the measurements deduced from these readings will only apply to a flight if the background illumination is constant - or only slowly varying.

A rough approximation to actual flight conditions was made by erecting a beam which projected out from the edge of the laboratory roof. A pulley-wheel was fitted to the end of the beam and the whole

triangular network could thus be hoisted up to hang freely in the open air. Power supplies were provided through long lengths of flexible cable which hung loosely from the radio sonde. In this way the motion of the apparatus was not impeded and it could be set swinging and twisting. Intensity readings were taken for both the long and the short paths. In the case of the former, it was hoped that the stability of the optical path and the effect of varying background illumination would be demonstrated. The experiment was carried out on a bright summer afternoon with a lot of cumulus cloud in the sky. A typical set of figures is given below.

Path	Short Path	Long Path	Short Path	Long Path
Total	6832	6730	6840	6690
counts	6867	6719	6820	6693
for	6774	6700	6825	6731
10 pairs	6772	6773	6875	6863
of	6811	6735	6840	6726
measuring				
pulses				

The probable error in the counts for a single pair of pulses obtained from any total for ten pairs of pulses for the short path = ± 2.3 counts.

The probable error in the counts for a single pair of pulses obtained from any total for ten pairs of pulses for the long path = ± 3.4 counts.

From the above figures it would seem that the ratio of the light intensities over the long and short paths, can be measured with an accuracy of better than 1% during a flight using totals for ten pairs of measuring pulses. By taking the mean values for those totals over fixed height intervals, this accuracy could be improved.

The 5% variation expected in the intensity ratio due to the variation in ozone concentration during an ascent, should thus be detectable.

It might be mentioned here that tests were carried out to check the detection of ozone by the apparatus. The latter was suspended in a stair-well so as to allow the use of the ten metre absorption path and ozone was produced by running a high pressure mercury discharge in a quartz envelope. The ozone produced by the ultraviolet light was blown into the absorption path by means of a fan. As the distribution of the ozone in the absorption path must have been non-uniform,

no attempt was made to estimate the concentration by a chemical method.

The results were:-

	Initial Readings		Readings after 30 mins.	
	Long Path	Short Path	Long Path	Short Path
Total counts for 10 pairs of measuring pulses	2655	2682	4810	2613
	2649	2656	4785	2521
	2660	2655	4808	2473
	2696	2693	4821	2514
	2647	2670	4822	2502
Mean counts for 1 pair of pulses	266	267	481	252

This shows that the intensity of the long path was reduced by an amount equivalent to about 200 counts while the intensity over the short path remained nearly constant. The ozone content must have increased by around 0.05 cm. $[O_3]$ /Km.

CHAPTER 6.

PREPARATIONS FOR A FLIGHT AND LAUNCHING PROCEDURE.

See Plates 30 to 34.

In order that the operation of the radio sonde can be checked right up to the moment of release, the launching site must be beside the receiving station. A piece of ground, some 35 yards square, surrounded by buildings but close to the laboratory, is used. Since the apparatus is almost 300 feet long from top to tail, the days on which it can be safely assembled and released are limited to those on which the surface conditions are calm: since the transmitter has a limited range, the upper wind speeds also must be small. In addition it is desirable that the wind should not be westerly, thus driving the sonde out to sea and resulting in the loss of much valuable equipment.

Favourable weather conditions are seldom, if ever, experienced during winter when the winds at very great heights seem to be strong westerly ones. During the spring or early summer, however, there are indications that these winds die down and may even swing right round to come from the east until autumn when they revert to strong westerlies. The winds below these extreme heights vary from day to day and, in general, are favourable only after a period of

settled weather such as occurs when an anti-cyclone is centred near the British Isles. The lower atmosphere is most stable around dawn and the flights are planned to start about half an hour after dawn in order to utilise the heating effect of the sun to help to keep the instruments warm.

With the 30 Mc./s. transmitters, dawn had to be sufficiently early for the useful part of the flight to be completed before there was much traffic on the roads to cause electrical interference. By having flights on Sunday mornings the first two tests were completed while dawn was still fairly late.

The reception of F.M. signals on the 150 Mc./s. band is free from interference and no technical trouble would be experienced in flight on mornings when the sun rises late. The launching site, however, is in the middle of Edinburgh and, on such mornings, many people would observe the balloons and might attract undesirable publicity to the proceedings.

There is a great deal of work to be done on the morning of a flight before the instrument can be released and only by working to a time-table can the whole apparatus be made ready at the right time. The time taken by each process has to be known and every item required must be at hand when it is needed. It was found desirable to have duplicates of such things

as batteries, valves, motor units, rigging, fuses etc. and, in short, to be able to rectify any small breakdown which would otherwise cause the flight to be abandoned.

When a radio sonde has been built and put into working order, the local weather station is contacted each evening and data obtained on the upper wind speeds. There comes a time when the conditions are right and there is a good chance of their remaining so for at least 12 hours. The time of sunrise for the next morning is checked and the time-table adjusted accordingly. Sometimes dawn is late enough to allow the results of the 0200 hrs. G.M.T. weather flight to be assessed before preparations are started. The following is an expanded version of the time-table used for Flight V when, with sunrise at 6.30 a.m., take-off was timed for 7.0 a.m.

(1) The preparation of the ozone radio sonde.

During the period of waiting the apparatus is suspended in a convenient stair-well near the laboratory. This enables the long path to be kept in working order as well as all the rest of the instrument.

4.0 The weather is inspected for chance of rain. An anemometer on the tower indicates the wind strength.

4.0 to 4.30 Using dry batteries and accumulators carried on a trolley, a check is carried out to make sure that the apparatus is working properly. The voltages are adjusted to be as near as possible to the values which will prevail during the flight. The ground receiving equipment is automatically tested in this process and is then switched off, all except the standard A.F. oscillator which is left on to reach a steady temperature.

4.30 to 5.20 The flight batteries are filled, their voltages checked and the coating of oil added.

5.20 to 5.40 The resin mixture is made up with the exception of the accelerator. This is added later at a time determined by the estimated time of release.

5.40 to 6.0 The radio sonde and 'Onazote' lid are removed from their position on the lower triangle and taken to the laboratory where the tray of batteries is inserted into place. The stem of the light filter is broken to leave a small orifice. Having been filled for nearly an hour, the batteries can be checked on load. If satisfactory they are then covered with cellulose wadding. The drying agent is put into its container in the lid and the cover put on and

sealed with 'Cellotape'. At the appropriate time, the accelerator is added to the resin which is then mixed and poured into the heater tube and the latter clipped into place round the windows. The lid is put back on the framework.

6.0 to 6.30 This framework with the 'Onazote' lid is then replaced on the lower triangle and the alignment of the mirrors checked. To do this a large sheet of stiff white paper is placed on the top of the lid containing the windows. By means of marks on the paper and on the lid, the position of the windows is exactly known and a lamp unit is placed centrally over the large window to shine upwards towards the mirrors without directly illuminating the small window. A square of light reflected from each mirror can then be seen on the white paper and each mirror can be adjusted separately to throw its square exactly over the position of the small window.

When this is done the flight power supplies are connected in and the long path tested. A reading is taken at the receiving station and then the slit for the short path is adjusted to give roughly the same reading. A complete test is then carried out during which the control corrections are estimated.

6.30 to 6.55 The whole triangular network with the ozone radio sonde attached is carried outside

and connected to the rigging. This is done in one journey by three men and requires a great deal of care to avoid disarranging the mirrors. Once the apparatus is suspended from the rigging a second complete test is made after which the insulating box is slipped over the radio sonde and caught on to the lid. The aerial support is pushed into its socket, the aerial fixed to it, and 'Cellotape' used to seal up the junction between the support and the 'Cellophane' skin. A final check is then carried out and a stop watch started as the second hand of the clock at the receiving station is registering a minute.

7.0 By this means the release can be timed to start when the receiving clock is exactly at a minute, thus simplifying later calculations. The temperature of the outside air is read at the time of release.

(ii) The balloons and rigging.

While the radio sonde is being prepared, the balloons are filled and then the rigging assembled and hoisted just before the sonde is brought outside.

4.0 to 4.30. Lights are set up to illuminate a sheltered area outside the laboratory and this area is swept clean of abrasive materials and a large canvas sheet laid down on the ground. The filling line is arranged to run from the middle of the sheet to

the hydrogen cylinders contained in a rack just inside the building. All the equipment required in the filling operations and for the rigging is collected.

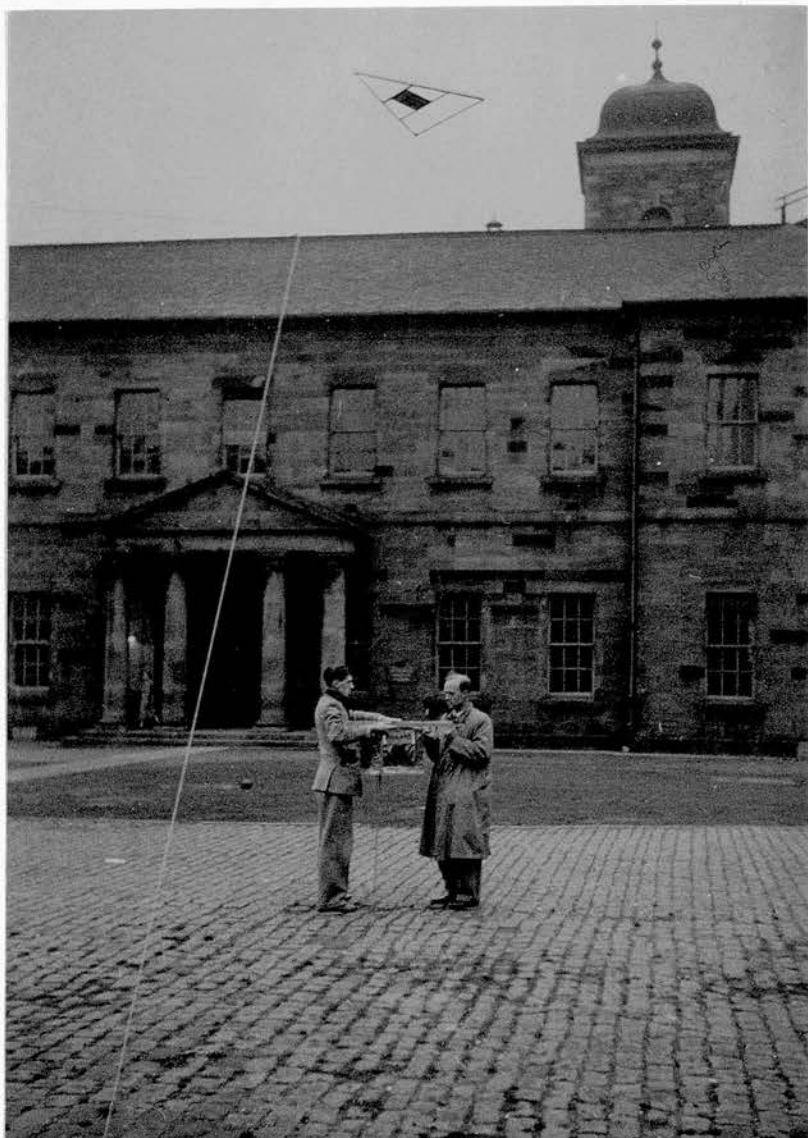
4.30 to 6.0 The three 4½ Kgm. balloons are successively filled and tethered (Chapter 3e).

6.0 to 6.30 The top balloons are raised by releasing their ropes hand over hand. When the attachment for the third balloon is reached, this balloon is also let up slowly. All knots, release mechanisms and loops are tested before the strain of the balloons is allowed to reach them. Since the parachute cannot be raised hand over hand without buckling the aluminium hoop, a steel ring is tied to the rigging just above the top of the parachute. A rope is passed through this ring and is used to raise the parachute until the junction of its six cords can be grasped. The lengths of these cords are carefully adjusted beforehand in order that each takes an equal strain and so the aluminium hoop remains circular and prevents the cords becoming entangled during the flight.

6.30 to 7.0 The triangles are connected up to the rigging and hoisted using the same device as for the parachute. After the electronics have been checked, the apparatus is held by the lower triangle while the

rope is pulled clear of the ring. The seconds remaining before the time of release are counted out to the person holding the lower triangle and he endeavours to position himself directly under the balloons as 'zero' is called and he lets go.

The apparatus is not tracked during the flight and recovery is dependent upon someone finding the wreckage. A waterproof envelope which can be seen in Plate 31 is tied in a prominent position on the apparatus and contains instructions for dealing with any inflated balloons, warning of leaking battery acid, and other such directions. There is also a stamped, addressed postcard on which the finder is asked to fill in particulars of where the apparatus can be collected. A reward of ten shillings is offered and the finder is asked to carry the apparatus to a place of shelter if that is at all possible. In the many flights undertaken from Edinburgh with cosmic ray apparatus and with the ozone instrument, it is reckoned that every apparatus which came down on land was recovered.



-Plate 30.-

The complete ozone apparatus just after it has been attached to the rigging. Part of the lift of the balloons is being taken by the rope on the left of the picture. The top triangle with the mirror support is clearly seen.



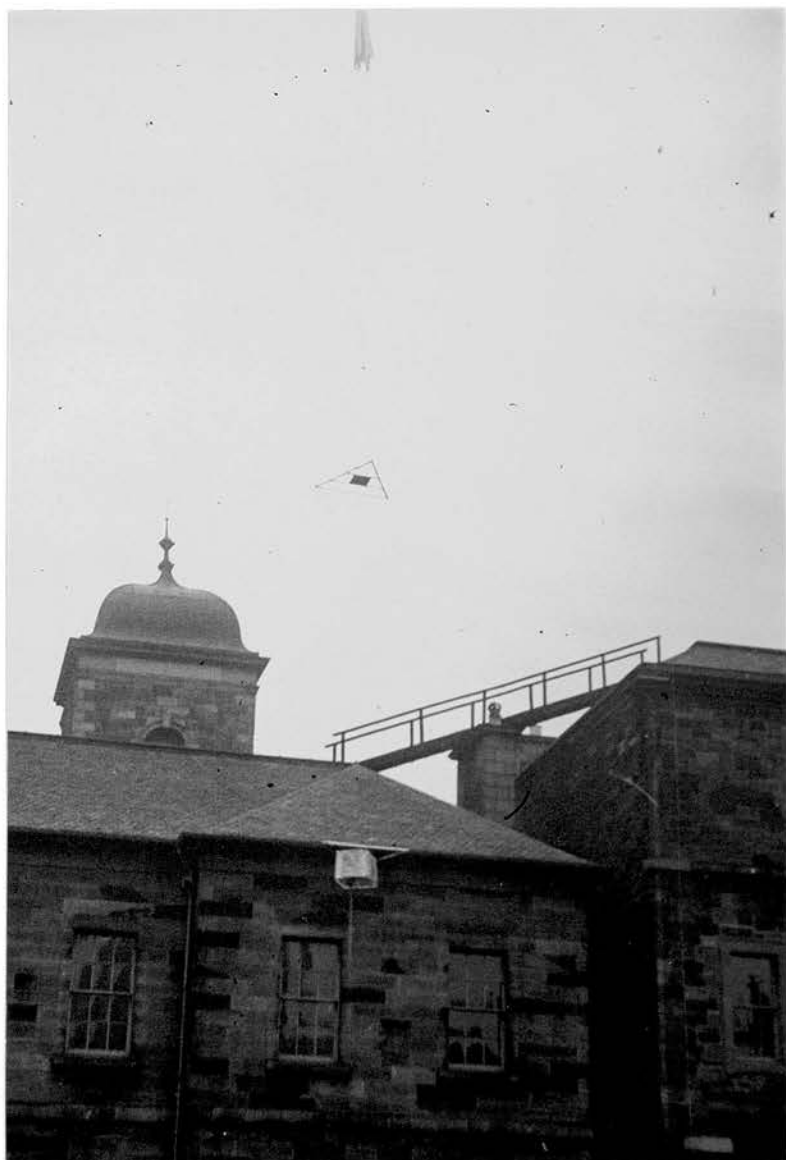
-Plate 31. -

A close-up view of the lower triangle showing the radio sonde container, reward label, aerial support and the six wires of the suspension.



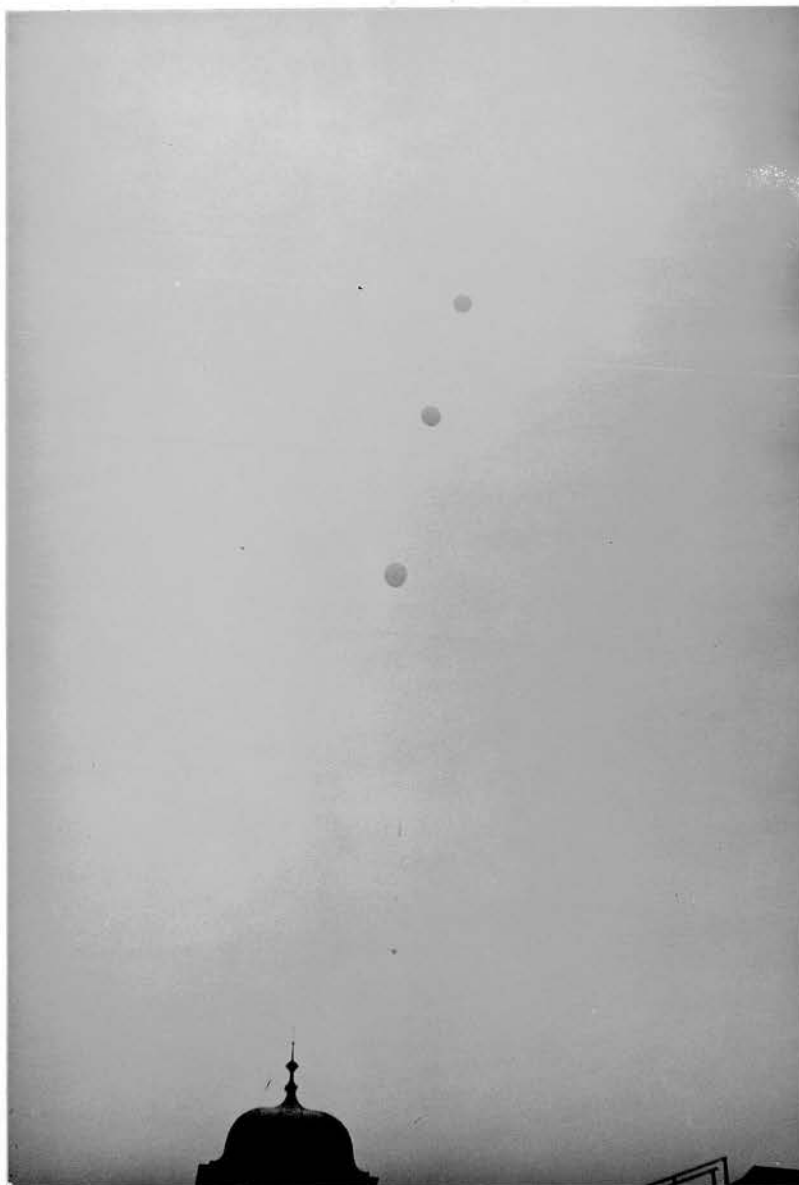
-Plate 32. -

The top triangle, parachute and balloons. The difference in height between the balloons may be judged from their relative sizes.



-Plate 33-

The moment of release. From top to bottom can be seen the parachute, aluminium hoop, ball-race, top triangle with mirrors, and the bottom triangle with the radio sonde and its aerial.



-Plate 34-

The complete equipment soon after release.

CHAPTER 7.

FLIGHT RESULTS.

Flight I. This was a flight in which the following items were tested:-

- (i) the temperature stability inside the 'Onazote' insulating box.
- (ii) the use of the triangles and their connecting wires as the transmitting aerial.
- (iii) the quality of reception on the 30 Mc./s. waveband and the ability of the ground circuits to handle low signal to noise ratios.
- (iv) the handling of the triangles on the ground before launching.

No ozone measurements were attempted but measuring pulses were simulated by a neon tube arrangement. The complete circuit is shown in Fig. 31. The transmitting valve was an HL 23 triode in a Hartley circuit oscillating at 27.5 Mc./s. Grid modulation was used, producing mainly amplitude modulation in the transmitted signal. The depths of modulation were 30% for the audio signal and more than 100% for the pulses, no values intermediate between 30% and 100% being possible with this simple circuit.

The apparatus was released at 0830 hours G.M.T.

Flight I.

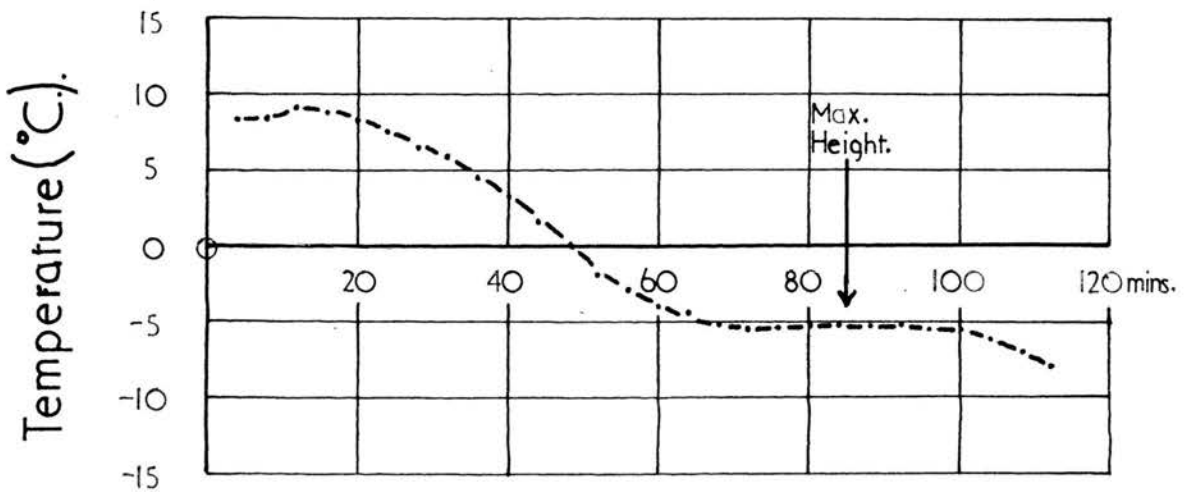
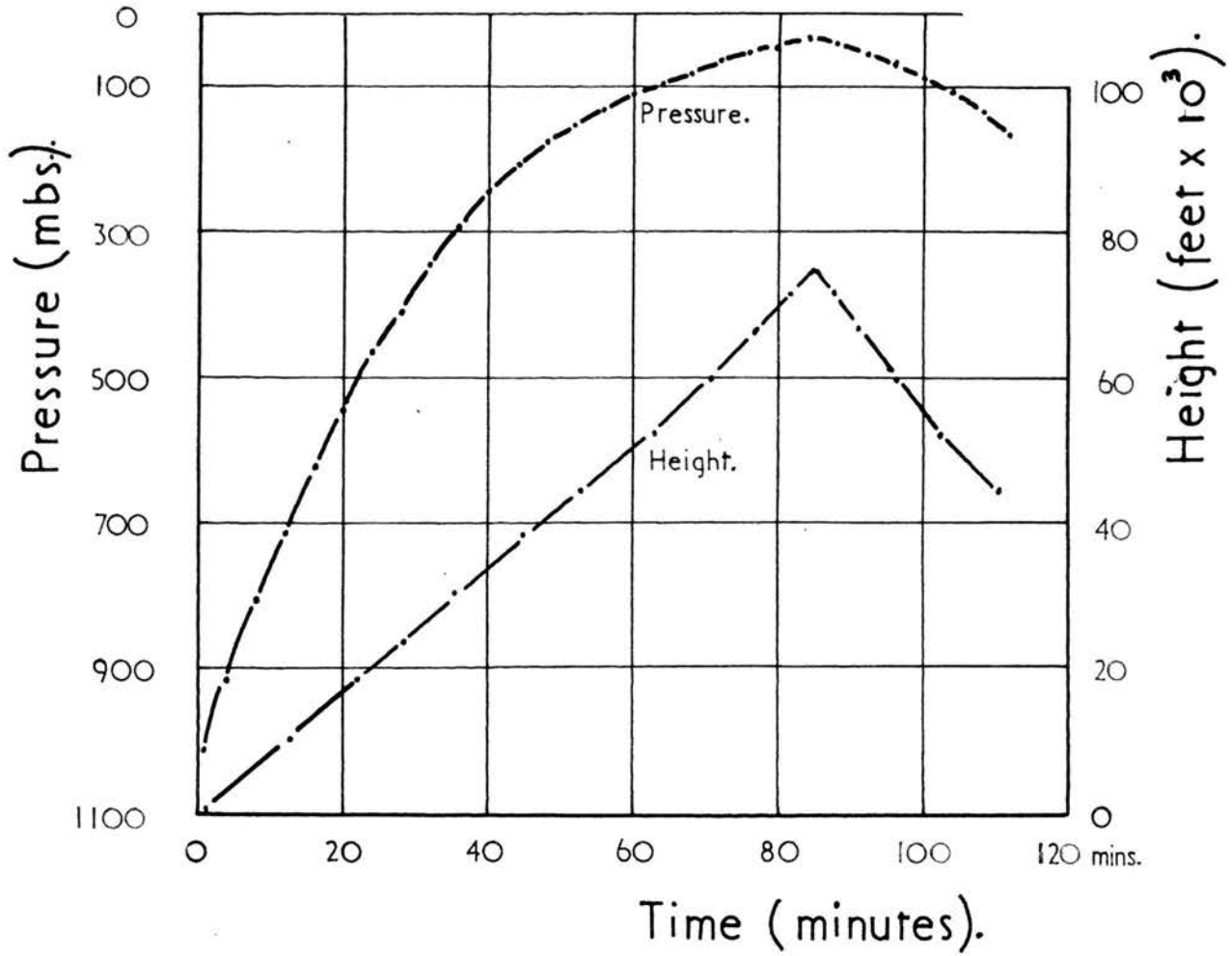


Fig.32.

on Sunday 1st March 1953 and reached a maximum height of 75,000 feet at a mean rate of ascent of around 860 ft./min. The total weight of the apparatus was 4.6 Kgm. and two 700 gm. balloons were used, each with a free lift of 720 gms. One balloon was still inflated when the apparatus landed at Coldingham, Berwickshire.

Fig. 32 shows the pressure-time, height-time, and temperature-time characteristics for the flight. It is noticed that the temperature inside the container fell to -8°C . While this was considerably above the outside temperature (-62°C), it was still lower than desirable for the ozone radio sonde whose inside temperature had to be kept higher than 0°C .

The signal received on the ground weakened considerably as the apparatus ascended and the pulses could not be separated from noise after a height of 40,000 feet had been reached. The signals did not increase in strength on the descent as was expected since the batteries would not have deteriorated significantly since filling.

It was concluded that the radiations from the six wires of the aerial must have been interfering with each other and so a single wire would have to be used to provide a sufficiently strong signal when the apparatus was at some distance from the receiving

station.

It was decided that the triangular network should be attached to the rigging in one piece in the next flight instead of being assembled in the open.

Flight II. In a second test flight, the same apparatus was used but a trailing wire 19 feet 6 inches long was used as an end-fed, half-wavelength dipole. The 'Onazote' box was covered with a double layer of 'Cellophane' to help to keep the inside temperature from dropping. This flight took place on Sunday 19th April, the take-off being at 0605 hours G.M.T. This time an altitude of 44,500 feet was reached at a mean rate of ascent of 900 ft./min. before one balloon burst and the apparatus descended at Innerleithen, Peeblesshire.

Fig. 33 shows the height and temperature records and a marked improvement is noticed in the latter over the temperature graph of the first flight. The signal strength was also much better but, after about 27,000 feet, a rhythmical rising and falling of the signal made it difficult to adjust the pulse circuits on the ground. This fading was clearly due to the aerial swinging below the radio sonde.

As it was impossible to make the long aerial required for the 30 Mc./s. transmission rigid, and as

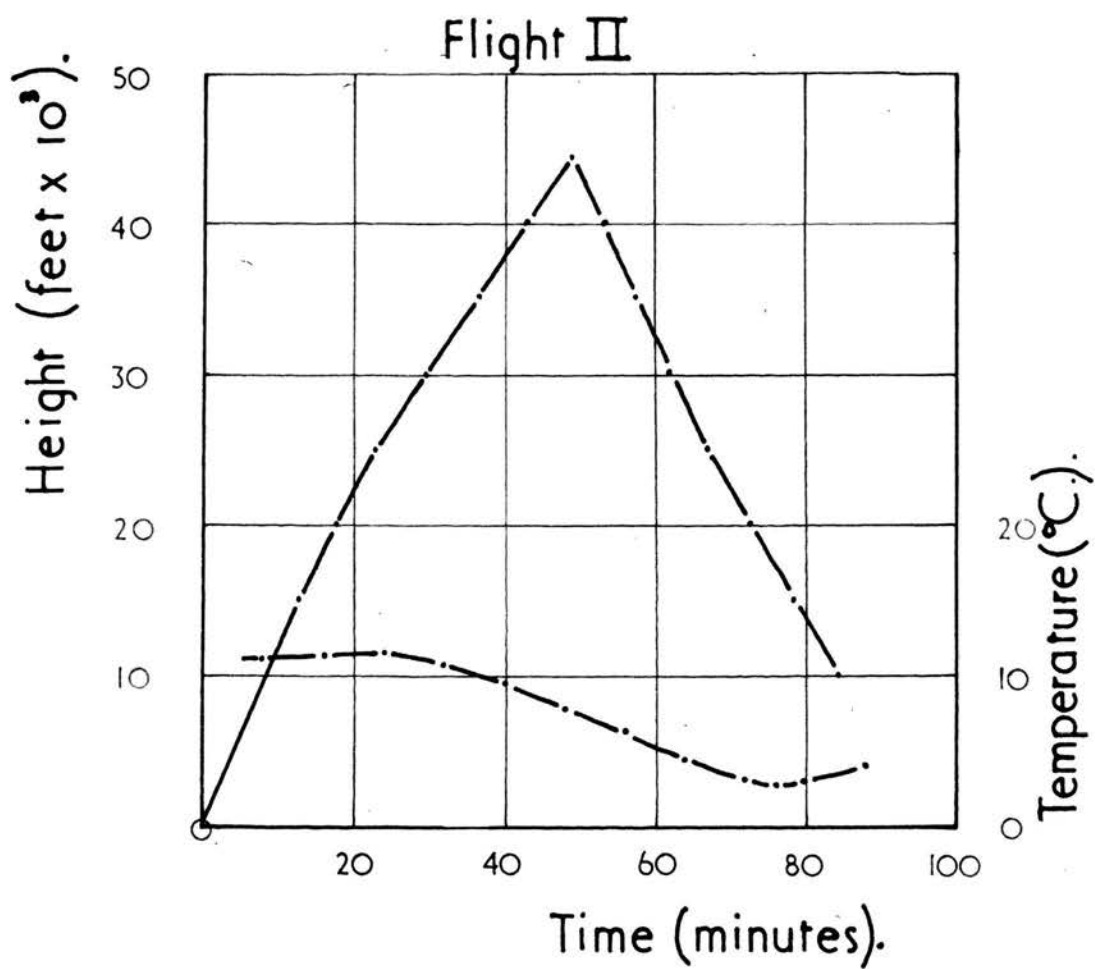


Fig.33.

Height and Temperature Records of Flight II.

electrical interference was very troublesome at this frequency, a test flight was then carried out using a 150 Mc./s. transmitter.

Flight III. A very light apparatus was built with no temperature element or motor-driven switch. No pulses were simulated and the triangles were not included in the rigging. Hence this flight was purely a test of the signal to noise ratio obtainable on 150 Mc./s.

The circuit diagram is shown in Fig. 34 where the acorn transmitting valve, oscillating at 152 Mc./s., is grid-modulated. The circuit elements were adjusted to produce a large amount of frequency modulation in addition to the amplitude modulation. The aerial was a 36.7 inches long, half-wavelength, vertical dipole whose end was coupled directly on to the anode end of the transmitter coil. This length was small enough to allow the use of a rigid support. The whole apparatus weighed 2 Kgm. and, although one 700 gm. balloon would have been sufficient, two were used, each filled to give a free lift of 2 Kgm. so that there would still be lift even if one burst.

The apparatus was released on Thursday, July 9th at 0428 hours G.M.T. and reached a maximum altitude of around 80,000 feet at a rate of ascent of 1070 ft./min.

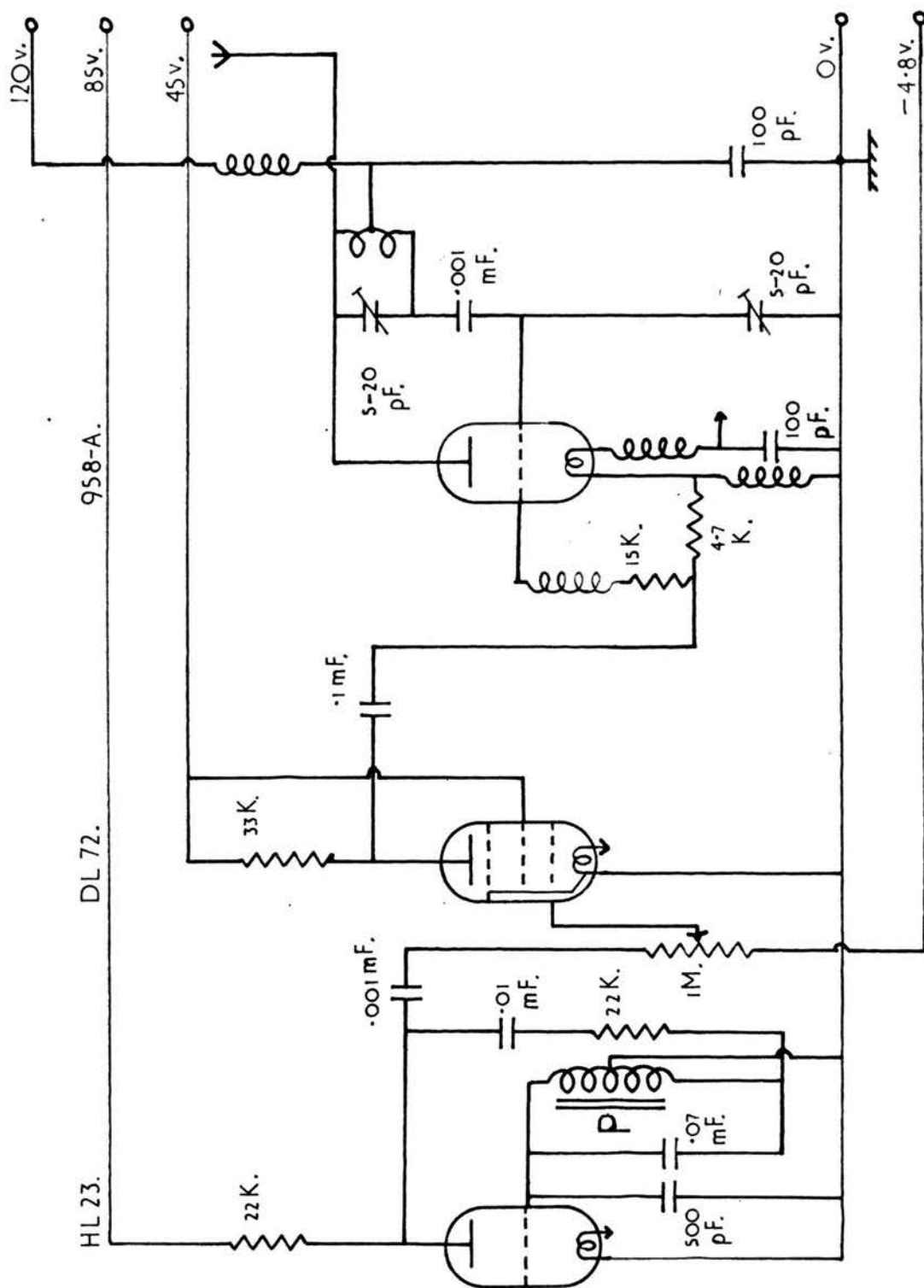


Fig. 34.
Circuit used in Flight III.

It was not recovered but this had been anticipated from the wind directions obtained the previous night. While the flight was in progress, the opportunity was taken of tuning the ground aerials for maximum signal.

Both the A.M. and F.M. signals were very good but the latter had much the better signal to noise ratio and was considered satisfactory for the ozone sonde. The adjustment of the trimming condensers in the transmitter circuit to produce maximum frequency modulation was, however, very critical and was not stable for long periods. Hence a different transmitter, anode-modulated by a second acorn triode, was designed and used in the later flights.

Flight IV. This flight commenced at 0640 hours G.M.T. on Sunday, 6th September 1953 and was the first trial of the complete ozone radio sonde. In this particular apparatus, the thermally insulating box was made of 'Aero Jablex' and no attempt was made to heat the windows which were separated by air dried by silica gel contained in a cell in the lid of the instrument. The lamp was one made up using anode and filament seals constructed by the late Mr. Dymond. A new filament assembly was fitted and sealed into the main tube which had new side-tubes appended.*

* Thanks are due to Mr. Broome of the Chemistry Department for performing the quartz-blowing.

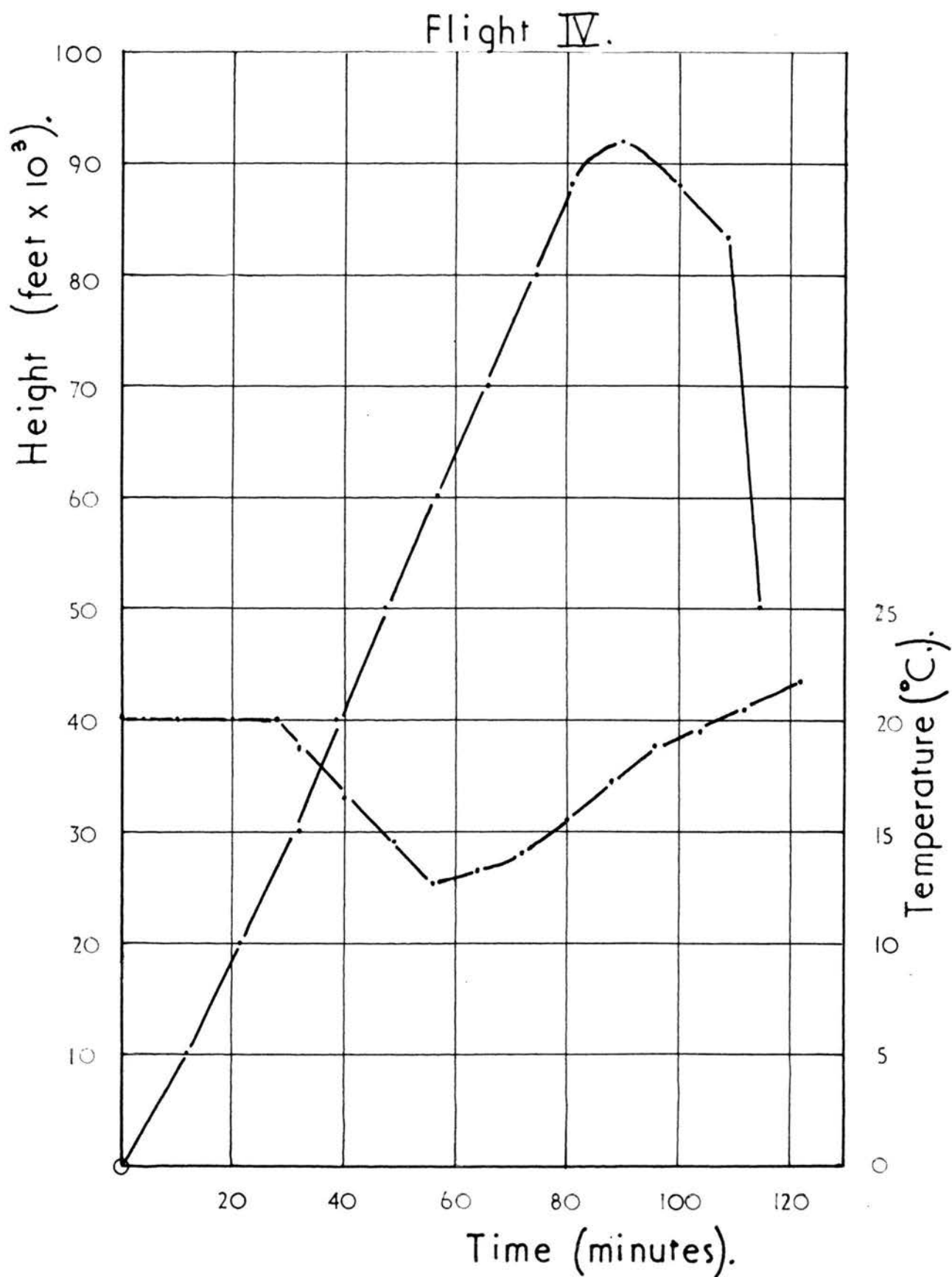


Fig. 35.

Height and Temperature Records of Flight IV.

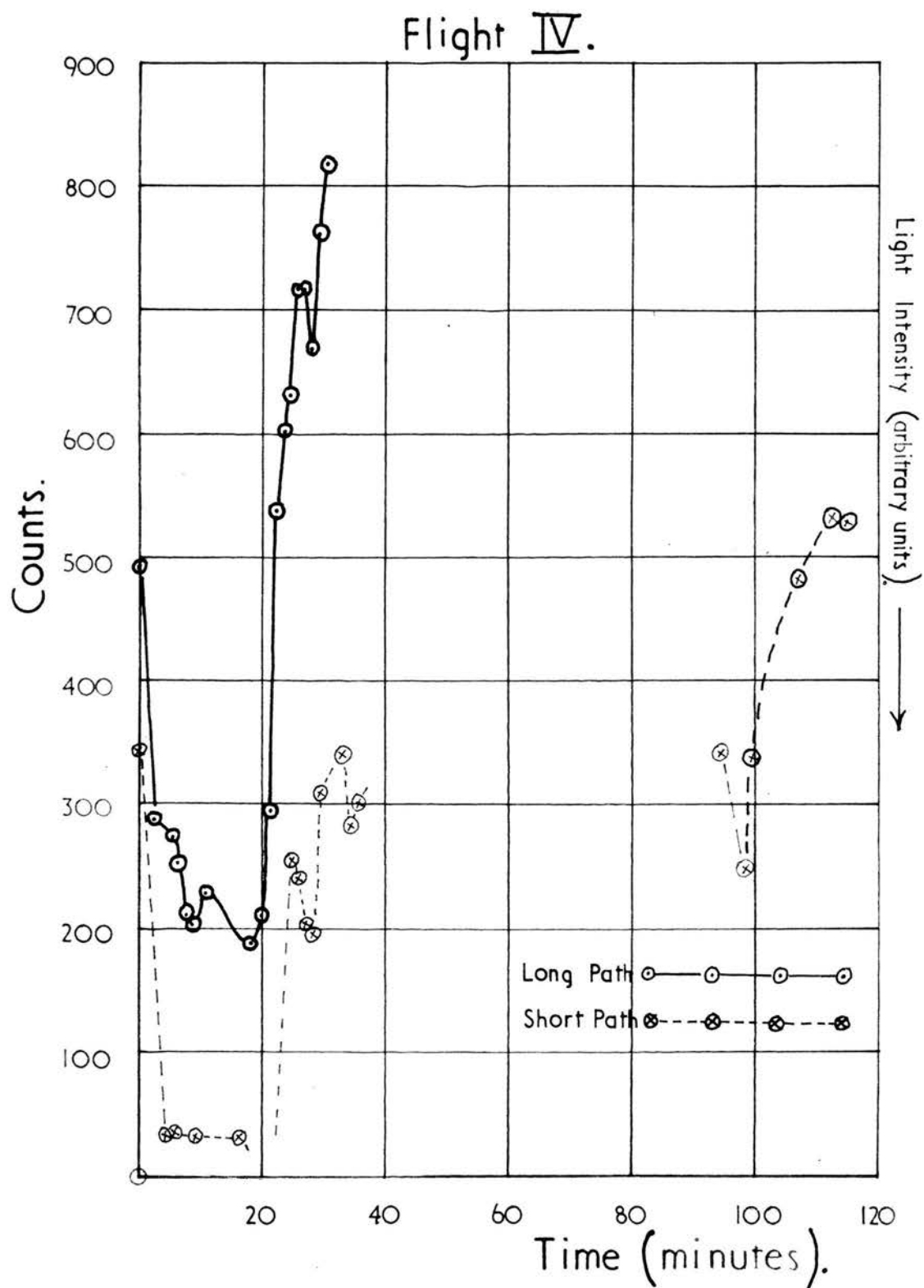


Fig. 36.

Intensity Measurements of Flight IV.

Unfortunately the anode to filament distance was slightly more than $1\frac{1}{2}$ inches and this raised the striking voltage and made the setting of the filament voltage rather critical. The apparatus weighed 11 Kgm. and the three $4\frac{1}{4}$ Kgm. balloons were each inflated to have a free lift of 830 gm. These lifted the instrument to 92,000 feet (28 Km.) at an average rate of 1,090 ft./min. The height and temperature records are shown in Fig. 35. The temperature is seen to vary only by 7.5°C . during the useful part of the flight.

In Fig. 36 (see also Figs. 39a and 39b), the counts obtained for the long and short paths are plotted against time from release. It is seen that there are large variations in both traces which have the same form except at around 100 minutes when the long path is absent. The working range of the telemetering system corresponds to a range of 20 to 850 counts, and the voltage output of the photocell amplifier has evidently been too low after 30 minutes to produce two measuring pulses. In such a case only single pulses are produced. Single pulses also occur if the amplifier output is too high and, to distinguish between the cases of the voltage being too high or too low, the pairs of timing pulses have

to be observed either diverging or converging before the single pulse stage is reached. During this flight, single pulses were obtained on the short path after 20 minutes due to the voltage being too high and on the long path after 30 minutes due to the voltage being too low.

At least part of the cause of the variations was the fact that the lamp flashing frequency fell off gradually with time until, at 50 minutes from take-off, the P.R.F. was a few pulses per minute. Fortunately, after about 90 minutes, the P.R.F. started to quicken and measurements were made on the counts for the short path. The long path, however, yielded only single pulses.

The cause of the behaviour of the lamp is uncertain since the apparatus was never recovered and must have fallen in the sea (the upper winds had veered slightly from the previous night). A possible explanation is that the internal resistance of the battery supplying the lamp filament, fell after the rheostat had been adjusted. The lamp filament voltage would then have been a little too large until the discharge had been running for some time.

In this particular lamp the intensity was very dependent on filament voltage and the flashing rate.

Due to the faulty lamp, few conclusions were possible from this flight but it was noted that the long path did not return with the short path. This was probably due to condensation on the windows interfering with the light passing over the absorption path. In view of this, additional precautions against condensation on the inside of the windows were taken in the next flight.

Flight IV proved that very good signals could be obtained from the new transmitter and that the temperature of the inside of the container could be kept reasonably constant. Useful experience was gained with respect to the best methods of handling the rigging on the ground.

Flight V. The instrument used in this flight was almost identical with that used in Flight IV, but contained a device for heating the windows: in addition, the air between the windows was dried with phosphorus pentoxide. Also the lamp was much more reliable than the one used in Flight IV and, indeed, was the one used for all the tests described in Chapter 5b.

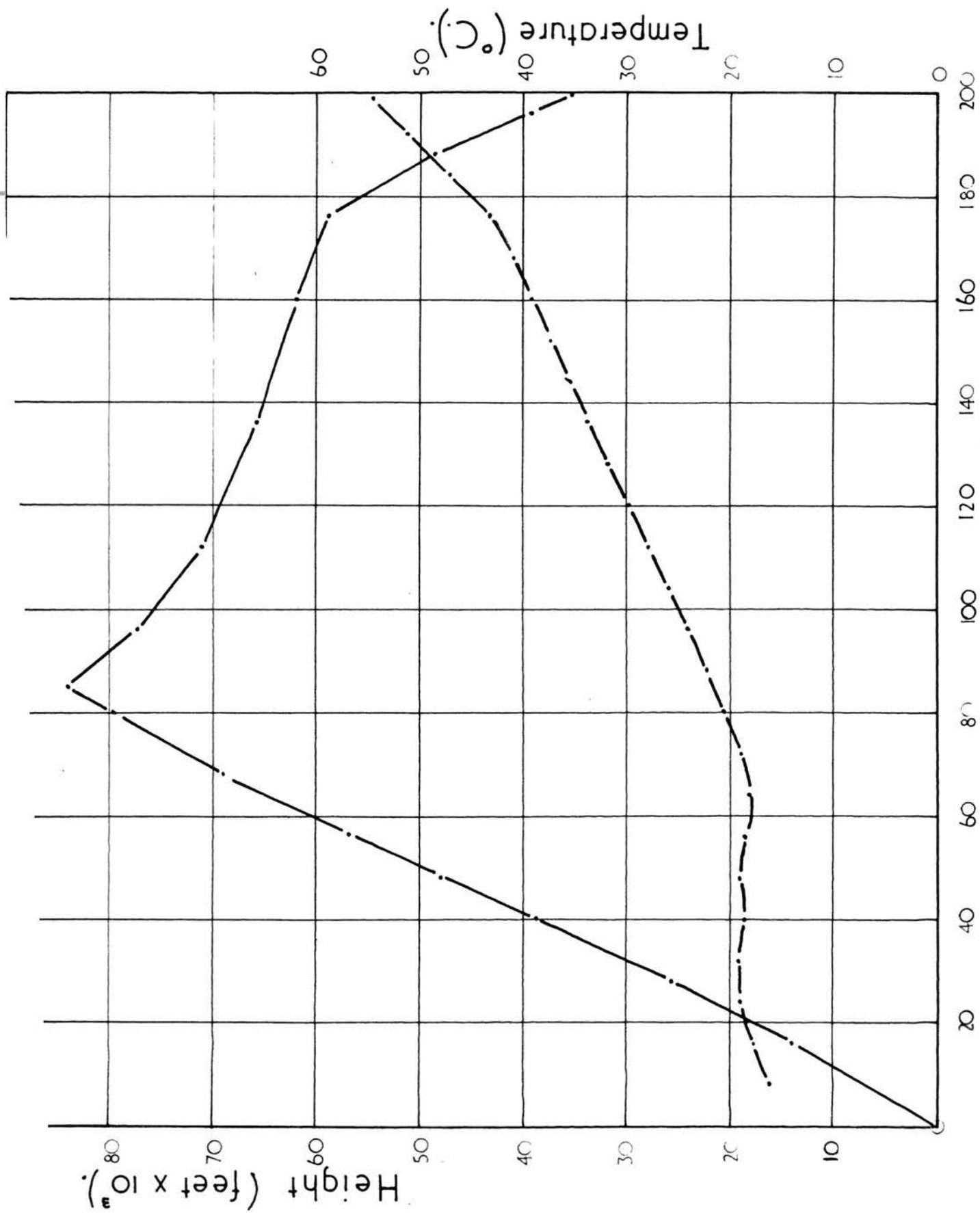
The weight of the apparatus was just under 11 Kgm.,

made up as shown in the following account.

	<u>gm.</u>
Wt. of the actual radio sonde	3140
Wt. of batteries, plugs, packing and filling	2300
Wt. of insulating container, aerial support and heater tube	2120
Wt. of drying agent and heater resin	180
Wt. of two triangles, connecting wires, mirrors, supporting strings and ballrace	1800
Wt. of parachute and associated rigging	755
Wt. of remaining rigging	493
	<hr/>
Total Weight	10,788
	<hr/>

	<u>gm.</u>
Wt. of balloon filling connection	476
Weights added	4000
• • Lift per balloon	4476
Load per balloon	3600
• • <u>Free Lift per balloon</u>	<u>880</u>

The apparatus was released at 0720 hours G.M.T. on Thursday, 8th October 1953, and reached a maximum height of 84,000 feet at a mean rate of ascent of 990 ft./min. The height and temperature records are



Height and Temperature Records of
Flight V.
Fig. 37.

shown in Fig. 37. From the height-time graph the falling-off in the rate of ascent just below 70,000 feet seems to indicate that a leak developed in one of the balloons. One balloon must have burst at 84,000 feet and a second at 60,000 feet, on the way down. The apparatus then descended on one balloon to land at Norham, Northumberland, after a flight lasting 4 hours.

The temperature graph does not show the usual fall at about 25,000 feet characteristic of the previous flights. This is considered significant and a comparison of the temperature graphs for Flights IV and V is taken to give an indication of the functioning of the heating tube in the latter flight. The very slow initial rate of descent has produced rather a large temperature variation in the later stages of Flight V. The correlation between the height and temperature records on the descent, including discontinuities at 176 minutes, seems to indicate that the outer surface of the 'Onazote' box, and the air in contact with it, became very hot due to the absorption of sunlight. During the descent this hot air would be sucked inside the container at a rate depending on the rate of change of pressure.

In a normal flight with ascent and descent rates of around 1,000 ft./min., this temperature variation

would not occur to such a marked extent but it may be that, when a heating element is included, the insulating box can be used without its 'Cellophane' covering.

Special precautions were taken with the lamp adjustments in Flight V. With the apparatus hanging in the stair-well, the lamp was tested for 15 minutes using the flight batteries before the filament voltage was set. The lamp worked perfectly, as was expected knowing that its light output was not affected very much by variations in the filament voltage. The L.T. supply for the lamp filament was more than adequate for the purpose and, since its voltage would remain constant for more than 3 hours, the lamp was expected to function perfectly throughout the flight.

During the testing of the apparatus when it hung in the stair-well, both the long and the short paths gave intensities which corresponded to counts within the double pulse range. Unfortunately, by the time the triangles had been taken outside and coupled to the rigging, a slight wind had arisen. This made a final check before launching difficult. The swinging of the transmitting aerial near to the ground and the movements of the crew tended to put the transmitter off tune. After release it was found that the time

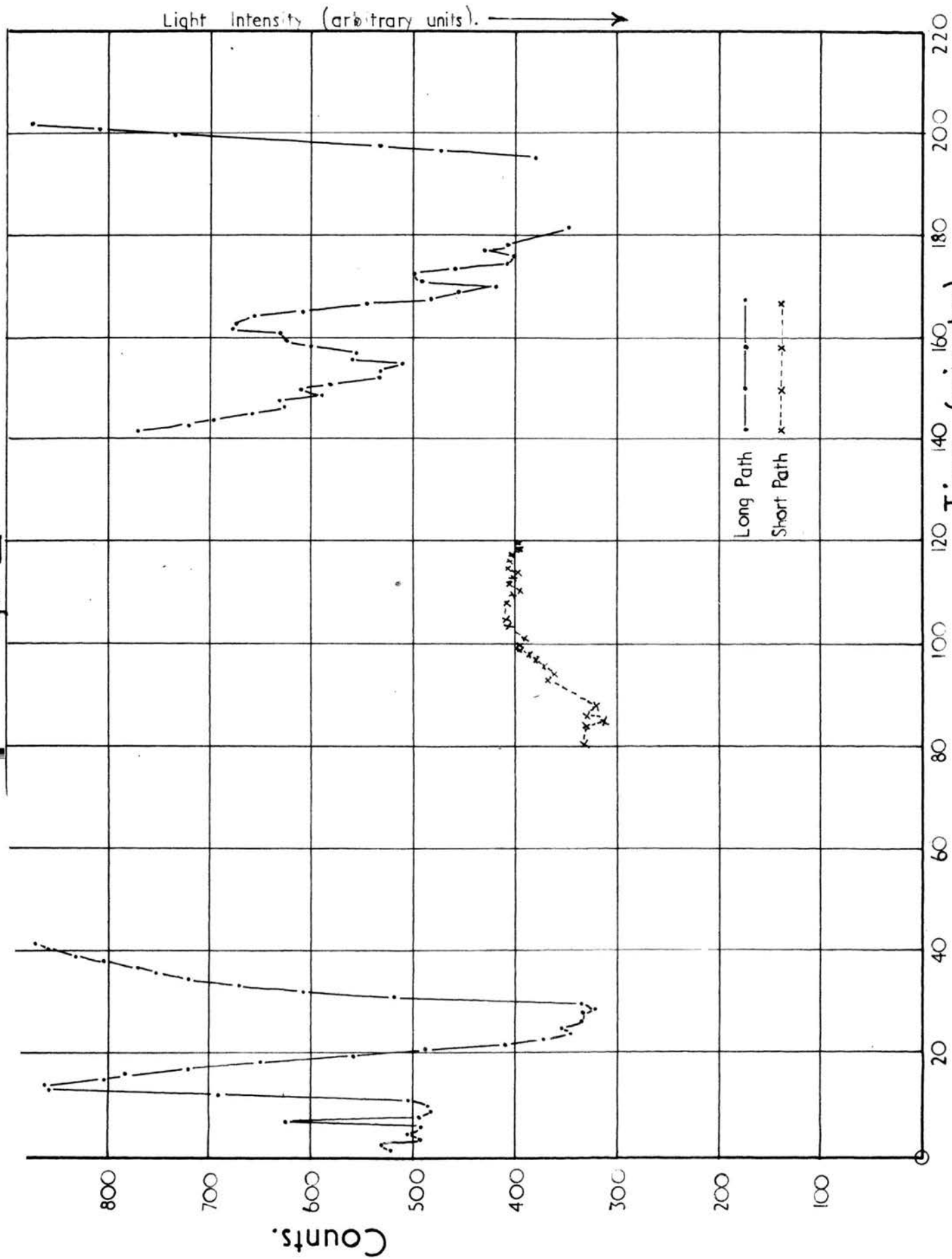


Fig. 38.

Intensity Measurements of Flight V.

separations of the pulses were very small and very soon the short path readings went off the range of telemetry altogether, the light intensity being just too large.

Fig. 38 (see also Figs. 39a and 39b) shows the counts for the long and the short paths obtained in Flight V. Since the short path readings were absent, except for a short period around 100 minutes after take-off, it is not possible to state definitely that the fluctuations in the long path counts were not due to variations in the light output of the lamp. As indicated above, however, the lamp intensity was unlikely to vary and this is borne out by two other considerations---

(i) If the initial variations in the light intensity over the long path had been caused by the lamp, the short path would have given double pulses since, initially, its light intensity was only slightly too great.

(ii) The P.R.F. of the lamp remained constant throughout the flight.

The light intensity over the long path has minima at 6 mins. and 14 mins. and goes off the measurable range at 41 mins. The minimum at 6 mins. is almost certainly due to a layer of stratocumulus at 5,000 feet. This was the only type of cloud reported

in the sky at the time of the flight.

The other minima can be explained by assuming that condensation started to form on the inside surfaces of the windows and then was driven off by the heater, only to return again as the latter began to cool down.

The accelerator was added to the resin mixture 65 minutes before the apparatus was released. By reference to the graph of the performance of the heater (Fig. 22) it is seen that this should reach its maximum temperature 85 minutes after filling, i.e. about 20 minutes after take-off. If it is assumed that the heater is only effective at its higher temperatures, the time scales of the heater characteristic and the long path counts fit in very well together.

It was really intended that the heater should become effective at a slightly greater altitude but a delay before take-off prevented this. The idea was that, if the heater started to be effective at 33,000 feet, the pressure of the air between the double windows would then be around 23 cm. Hg. and so the windows should remain free of condensation thereafter, due to the remaining heat being given off by the heater and pressure of the air between the windows diminishing.

The long path is seen to return at 140 minutes

when the temperature of the inside of the container is about 35°C . and when the pressure of the air between the windows is around 4 cm. Hg. and is slowly increasing along with the temperature. It may be that these conditions were conducive to the elimination of the condensation. There was a break in the measurements at 180 minutes and at 195 minutes the long path intensity is seen to decrease rapidly once more.

The short path appeared for a space of about 40 minutes while the apparatus was above 70,000 feet.

The following figures indicate the accuracy of the intensity measurements obtained for the long and short paths during the flight. They refer to periods in which the readings did not have large drifts.

The Short Path.

The table on page 138a includes 33 values for the total counts for 5 pairs of measuring pulses. The last three values were omitted and the figures taken in three groups of ten to give three mean values. The deviations from these means were calculated and the results on page 138b obtained.

The accuracy of these short path measurements is not so good as that calculated from figures obtained when the instrument was tested on the ground. It is still adequate, however, for the purpose of estimating ozone concentration.

Time from take-off	99°50"	101°	103°20"	104°30"	107°55"	109°5"	110°10"	111°15"
Total count for 5 pairs of pulses	2069 2006 1949 1878	2018 2027 1890 1886	2039 2158 1915	2154 2027 2074 1936	2119 1959	2023 1999	1986	2027
Mean value for 5 pairs of pulses	1976	1955	2037	2048	2039	2011	1986	2027
Counts for 1 pair of pulses	395	391	408	410	408	402	397	405
Time from take-off	112°30"	113°40"	114°45"	115°50"	117°	118°15"	119°20"	
Total count for 5 pairs of pulses	2043 1990 1990	1995	2040	1999 2063	2044 1989	1970 1992	1991	
Mean value for 5 pairs of pulses	2008	1995	2040	2031	2017	1981	1991	
Counts for 1 pair of pulses	402	399	408	406	403	396	398	

Figures for the Short Path - Flight V.

Time	99'50" → 103'20"	103'20" → 110'10"	111'15" → 117'
Mean value for 5 pairs of pulses	1992	2019	2018
Probable error in mean	± 19	± 17	± 6
Counts for 1 pair of pulses	398 ± 4	404 ± 3	404 ± 1

Summary of Figures for the Short Path - Flight V.

Time from Take-off	14° 45"	15° 50"	16° 45"	18°	19° 10"	20° 15"	21° 20"	22° 30"	23° 30"	24° 45"	25° 55"	27° 10"	28° 20"	29° 30"
Total counts for 5 prs. of measuring pulses	3882 4049 3974 4147	3951 4007 3880 3882 3862	3771 3433	3096 3645 3381 3147 2961	3000 2599 2681 2781 2901	2550 2439 2450 2394 2342	2049 1952 2110 2082 2025	1942 1833 1880 1794 1825	1548 1643 1783 1709 1741	1836 1747 1750 1684 1732	1650 1756 1563 1663 1722	1652 1663 1683 1655 1654	1544 1639 1576 1595 1631	1625 1653 1705 1670 1690 1675
Mean	4013	3916	3602	3246	2792	2435	2044	1855	1686	1750	1671	1661	1597	1670
Probable error in mean	\pm ?	\pm 18	\pm ?	\pm 81	\pm 48	\pm 23	\pm 18	\pm 17	\pm 25	\pm 17	\pm 22	\pm 4	\pm 12	\pm 7
Counts for 1 pair of pulses	803 \pm ?	783 \pm 4	720 \pm ?	649 \pm 16	558 \pm 10	487 \pm 5	409 \pm 4	371 \pm 3	337 \pm 5	350 \pm 3	334 \pm 4	332 \pm 1	319 \pm 2	334 \pm 1

Figures for the Long Path - Flight V.

The Long Path.

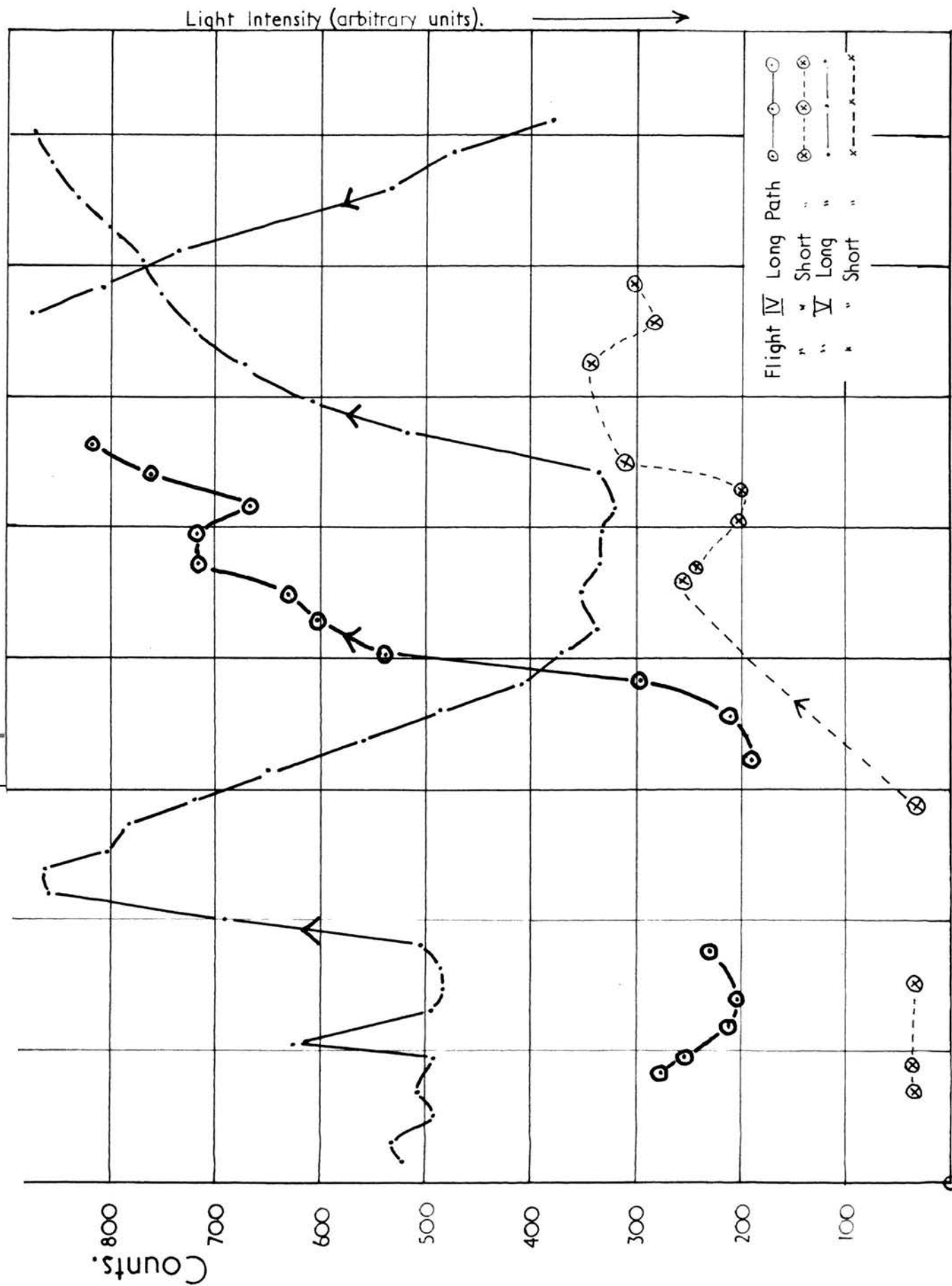
The results on page 138c indicate that the light intensities over the long path can be measured and telemetered to ground with sufficient accuracy. They show that the triangles must be stable and that stray light cannot have been affecting the photocell.

In Flight V the strength of the reception was very good indeed and it was very encouraging to find that measurements could still be made $3\frac{1}{2}$ hours after release when the apparatus was a considerable distance away from the receiving station and when the transmitter battery must have run down by more than 20 volts. No trouble was experienced from stray pulses due to electrical interference.

After recovery the apparatus was tested and found to be in perfect working order except that a resistor in the pulse mixing stage had been affected by battery acid spilt on landing. This resistor could not have been faulty during the flight since then no pulses would have been transmitted at all. The calibrations were checked and found to be unchanged.

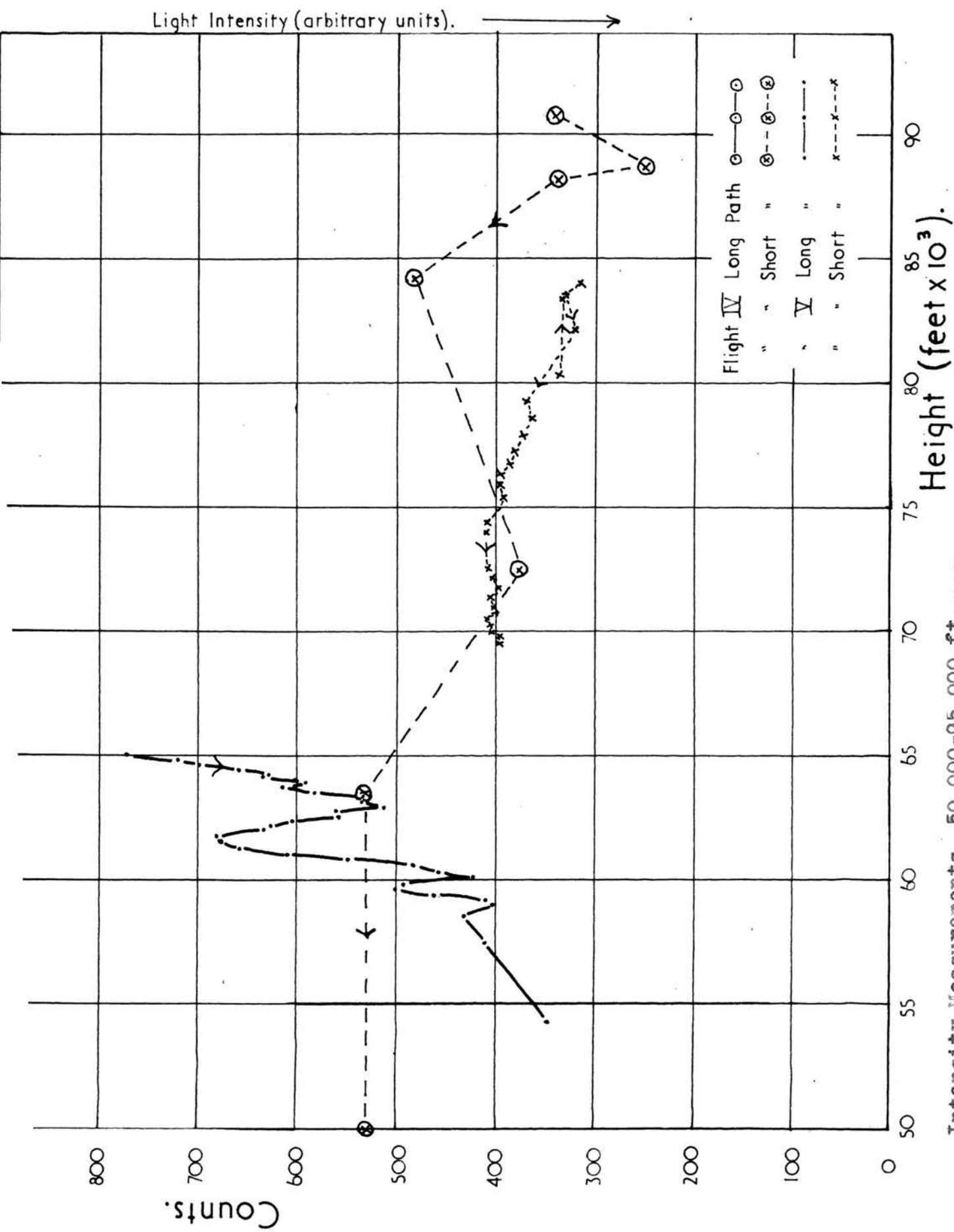
It was concluded that the electronics of the apparatus functioned perfectly and that all the telemetering was performed with the requisite accuracy. However the light intensities themselves were affected by some factor, or factors. Condensation on the

windows probably upset the absorption path readings but something else must have caused the brief appearance of the short path at the highest altitudes. All the evidence obtained in Flights IV and V, and in control experiments is critically surveyed in the next chapter.



Intensity Measurements, 0 - 45,000 ft., of Flights IV and V.

Fig. 39a.



Intensity Measurements, 50,000-95,000 ft., Fig. 39b.
 of Flights IV and V.

CHAPTER 8.

DISCUSSION OF THE INTENSITY MEASUREMENTS

The intensity measurements made in Flights IV and V are summarised in Figs. 39a and 39b which show the corresponding counts plotted as a function of height. Clearly the variations are too large to be due entirely to absorption by atmospheric ozone.

As described in the last chapter, there were indications in Flight V that condensation on the windows might be the main factor involved but this did not explain the brief appearance of short path intensities within the telemetering range at the highest altitudes. In an attempt to clarify the situation, each section of the recovered instrument was investigated with a view to the possibility of its causing large drifts in the intensity measurements.

The lamp. Laboratory tests showed that the intensity of the lamp was not significantly affected by small changes of temperature. The temperature of the lamp did not vary by more than 8°C on the ascents and there is no correlation between the intensity and temperature graphs.

In Flight V the pulsing rate of the lamp was

practically uniform for the entire flight and so the drop in battery voltage must have been small and no variation would be expected from this source. The 200 volt line supplying the H.T. for the lamp was well insulated and it was thus unlikely that corona could occur at low pressures. Any fluctuations in the voltage across the lamp would have been accompanied by the transmission of stray pulses. None were observed in either flight.

It is known that the ultraviolet light from the lamp produces some ozone in the air immediately surrounding the lamp. This effect was regarded as negligible but tests were carried out to see if the ozone could possibly accumulate in the 'Onazote' container and reach a concentration sufficiently strong to cause noticeable absorption. The apparatus was run continuously for one hour in its container and no decrease in the intensity of light reaching the photocell was observed.

The section of the quartz tube in which the discharge occurs acquires a surface charge. If, while the lamp is pulsing, an object is brought near this part of the tube, the pulsing is arrested for a few seconds and is again temporarily stopped when the object is removed. The effect of this surface charge on the intensity of the lamp is very small and no

alteration is found when the lamp body is covered with a metal grid. The constancy of the lamp P.R.F. during Flight V would again seem to indicate that the lamp was not affected by this factor.

The mirrors. Since the mirrors are always slightly warmer than the surrounding air, except possibly at the greatest heights where there is practically no water vapour, it is unlikely that condensation would form on the mirrors during the ascents. It seems impossible that any disarrangement of the mirrors or of their support, through violent motion or contraction due to fall in temperature, could cause the smooth type of variation found in the intensity-height curves. Neither could the variations be explained by postulating some instability of the triangles and their connecting wires. All the indications are that the triangles are very stable.

The electronics. In the examination and testing of the recovered equipment of Flight V, the electronics were found to be in perfect working order. The variations in temperature were too small to cause any perceptible drift in the telemetering system and battery run-down certainly could not produce the effects obtained during the flights.

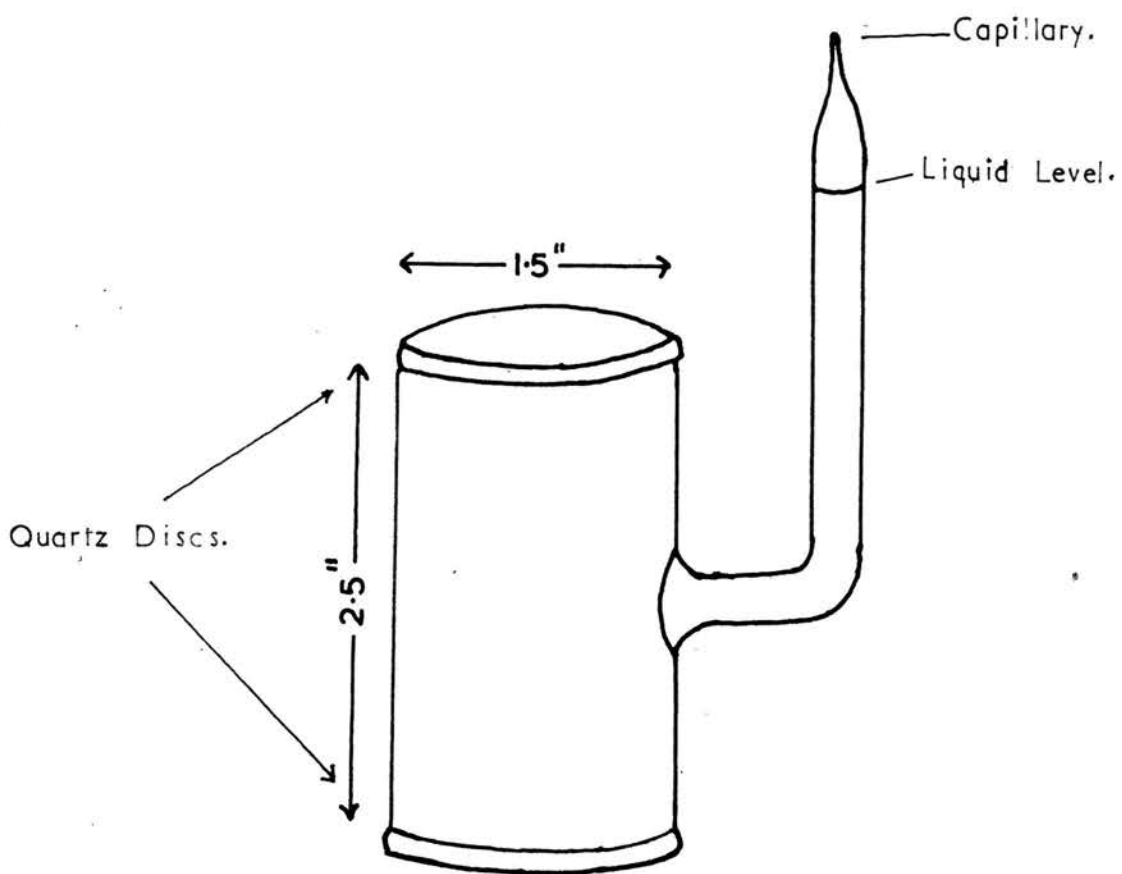


Fig. 40.

Diagram of Light Filter.

The light filter. The filter contained an aqueous solution of nickel and cobalt sulphate. Since the concentrations were small, the vapour pressure of the solution was very nearly the same as that for water itself (17.5 mm. Hg. at 20°C). This pressure is equal to the atmospheric pressure at around 85,000 feet. Since, however, there was only a very small hole in the top of the side tube, the liquid was not expected to boil. This was checked by placing the filter under a bell-jar from which the air was slowly evacuated. The liquid did not 'boil' but a similar though much more moderate effect occurred. At a pressure equivalent to a height of 48,000 feet, tiny bubbles were observed to be forming at the walls of the side-tube and at the top plate of the main tube (Fig. 40). As the pressure was further decreased the bubbles slowly grew bigger until, at the equivalent of 65,000 feet, they were about 2 mm. in diameter at the top of the main tube and had displaced an amount of liquid sufficient to cause a noticeable rise in the height of the meniscus in the side-tube. This process continued until at the pressure associated with a height of 85,000 feet, the liquid was being forced out of the top of the side-tube and, at the top of the main tube, there was now only one large bubble covering the whole width of the tube. The evacuation was carried down as far as was

possible, the minimum pressure reached being 1 cm. (equivalent height 94,000 feet), with the side-tube occasionally emitting liquid and also air bubbles.

When the pressure was allowed to increase slowly, the liquid immediately rushed back into the main tube and there was a good deal of bubbling, presumably in some process of equalising the pressures inside and outside the tube. This died down slowly and equilibrium was reached at an equivalent of around 42,000 feet with the main tube now only about $\frac{7}{8}$ ths. full.

The whole process was repeated using tap water instead of the filter solution with identical results. This action must have occurred in both Flights IV and V and, in the latter case, when the instrument was recovered, the filter was found to be about $\frac{2}{3}$ ths. full of liquid but some of the loss may have occurred in the landing and the subsequent movements of the instrument.

The effect of this action, which starts at 45,000 feet, on the intensity of the light reaching the photocell is uncertain. There are two processes occurring, one, the formation of bubbles, tending to decrease the light intensity and the other, the reduction of the path length in the solution, tending to increase the light intensity. The relative effects of the two processes must vary considerably and the

intensity measurements made at heights above about 45,000 feet cannot be related to the ones made during the ascents to this height.

Other Factors. On both the days on which Flights IV and V took place, there was a layer of stratocumulus at around 5,000 feet and this showed up in the intensity measurements on the latter flight. The variations higher up could not have been due to cloud, however, since there was none present at all above the stratocumulus.

No constituent of the atmosphere absorbs ultraviolet light in the region of 2537 A to anything like the same extent as ozone and so the intensity variations could not be due to absorption in the long path.

The photocell, whose angle of view is small, is not sensitive to the background lighting, unless the latter changes quickly, and so stray light cannot play a significant part in the intensity measurements.

From the above considerations it has been concluded that, during the ascent in Flight V, the variations in the intensity of the light traversing the long path were due to condensation forming on the windows. The analysis of the measurements made during the descent is more difficult and it can only be said that the light intensities must have been

affected both by condensation on the windows and disturbances in the filter, though the latter must have been slight during the initial stages of the descent when the short path gave readings for about 30 minutes in which time the intensity variation was quite small (Fig. 39b).

The filter could be made stable with respect to external pressure by sealing it off at atmospheric pressure. Some mechanical clamping device would have to be used, however, to keep the quartz windows from blowing off at high altitudes.

The problem of condensation is more difficult. The space between the windows cannot be evacuated completely since the glass would not withstand the air pressure at ground level. Neither does it seem, that the evacuation of this space to half atmospheric pressure would be effective since, in Flight V, the condensation started to return at 27,000 feet when the pressure was around 26 cm. Hg. Some form of 'windscreen-wiper' would be difficult to mount without seriously affecting the ease of assembly of the apparatus prior to a flight and it is doubtful whether this device would be successful in any case.

This leaves two alternatives - efficient heating of the windows throughout the flight or the complete

elimination of water vapour from the inside of the container. The latter would require the separation of the battery container from the main body of the apparatus and would probably entail a considerable increase in total weight. The relative humidity of the atmosphere was over 90% in the layers below 3,500 feet in both Flights IV and V and so some means of drying the air inside the container would be needed.

If an efficient heater could be designed, this would be the simplest way of keeping the windows free from condensation. Considerable research would have to be done to find a heater which would be easy to prepare before a flight and which would be effective for at least 2 hours.

Before having another ozone-measuring flight it would be necessary to carry out trial flights to test the new measures taken against condensation. These trial flights, to be of real value, would have to be made with apparatus closely resembling the complete ozone apparatus especially in such details as volume, surface area, heat capacity and moisture content. It would also be of value if the ozone apparatus could be tested while operating in an evacuated vessel in the laboratory.

CHAPTER 9.

CONCLUSION.

Lack of time prevented any more flights being made and, in any case, by the time the necessary preparations could have been completed, it would have been rather late in the year for flying. From the work described above it would seem that this type of ozone radio sonde is a feasible proposition. It is seen from the results obtained on the ground that the instrument is sufficiently sensitive to measure changes of ozone concentration of the magnitude of those which occur in the atmosphere: the intensity measurements made during Flight V show that this sensitivity is only slightly impaired by the conditions met with in a flight. When the efficiency of the optical arrangements has been brought up to the standard required by the accuracy of the intensity measurements, the instrument should be able to tele-meter accurate information from which the vertical distribution of ozone can be plotted against height as the apparatus ascends.

It must now be considered how well this apparatus complies with the specification laid down at the beginning of the work. This specification called for

regular ozone-height measurements using balloon-borne telemetering equipment which was to be as simple, inexpensive and easy to handle as possible.

It takes at least four months to build a complete apparatus and the cost of the materials used is around £50. The balloons add another £50 to bring the total cost to £100. The instrument is basically very simple but the adjustment of the rotating sector mechanism is difficult since the small electric motor will only operate if the friction in the two reduction drives, the meteorological switch and the shorting switch is reduced to a minimum. Only a breakdown in some component could cause any trouble with the electronics.

The main drawback in the apparatus is the difficulty in getting it off the ground. There are not many days in the year when the upper winds are slight and in a direction which gives a reasonable chance of the apparatus being recovered. The number of days on which flights are possible is still further cut down by the necessity of the ground conditions being very calm. Of course Edinburgh is not a very suitable locality for the site of the launching ground as the prevailing west winds blow the apparatus out to sea.

Taking into account the time required to build and calibrate a radio sonde and the few days in which flights are possible, it seems only two or three flights could be made in a year and it would take a long time before sufficient information could be compiled from which conclusions could be drawn regarding the relations between the vertical ozone distribution and other meteorological factors.

It may be, however, that this instrument could be of value in checking the ozone distribution deduced from ground observations on certain specific occasions. If the ozone radio sonde could play a small part in the development of a precise method of calculating the vertical distributions using observations from the Dobson spectrographs, then it would have proved valuable, since only by the latter method does it seem possible for regular determinations to be made throughout the year.

ACKNOWLEDGEMENTS.

This work was carried out in the Physics Department of Edinburgh University under the direction of Professor N. Feather, the late Mr. E.G. Dymond, and Dr. G.R. Evans.

The idea of the ozone radio sonde was conceived by Mr. Dymond whose experience of upper air research is greatly missed. The writer will remember him for his wise supervision and constant encouragement.

An expression of thanks is extended to the many people who helped in the carrying out of this work. Some have already been mentioned in the text. Others, including Mr. J. Dainty, Dr. G.R. Evans, Dr. J.C. Knight and Dr. R.P. Thatte gave much-appreciated assistance in the launching operations; Mr. J. Paton and Dr. J.D. Pullar gave valuable advice on meteorology and balloon techniques respectively. The help of Mr. Headridge and the technical staff of the Physics Department is gratefully acknowledged.

Thanks are due to the Department of Scientific and Industrial Research for a maintenance grant.

Components in First Filter Unit - Fig. 24.

Resistors:-

R1	20K	½ watt	R16	4.7K	¼ watt
R2	10K	½ "	R17	1K	¼ "
R3	1M	¼ "	R18	3.3K	¼ "
R4	200	½ "	R19	2M	¼ "
R5	20K	variable	R20	120K	¼ "
R6	10K	¼ watt	R21	2.7K	½ "
R7	10K	¼ "	R22	5K	5 "
R8	10K	½ "	R23	500K	¼ "
R9	22K	1 "	R24	380	¼ "
R10	1M	¼ "	R25	500K	¼ "
R11	200	½ "	R26	270K	¼ "
R12	5K	variable	R27	4.7M	¼ "
R13	100K	¼ watt	R28	1M	variable
R14	100K	¼ "	R29	270K	¼ watt
R15	100K	¼ "	R30	500K	¼ "

Condensers:-

C1	.1 mF	paper	C10	.001 mF	paper
C2	.05 mF	"	C11	.001 mF	"
C3	.1 mF	"	C12	.001 mF	"
C4	.02 mF	"	C13	.001 mF	"
C5	.005 mF	"	C14	.1 mF	"
C6	.01 mF	"	C15	.005 mF	mica
C7	.01 mF	"	C16	.005 mF	"
C8	.01 mF	"	C17	.0015 mF	"
C9	500 pF	mica	C18	20 pF	"

Inductors:-

Components in Final Filter Unit - Fig. 26.

Resistors:-

R1	4.7 K	½ watt	R13	22 K	1 watt
R2	1 M	¼ "	R14	200	½ "
R3	33 K	½ "	R15	5 K	variable
R4	20 K	½ "	R16	1 M	¼ watt
R5	10 K	½ "	R17	3.3 K	½ "
R6	1 M	¼ "	R18	18 K	½ "
R7	200	½ "	R19	68 K	2 "
R8	20 K	variable	R20	1 K	variable
R9	10 K	¼ watt	R21	600	¼ watt
R10	10 K	¼ "	R22	1.5 M	¼ "
R11	1 M	½ "	R23	1 M	¼ "
R12	10 K	½ "			

Condensers:-

C1	.1 mF	paper	C9	.01 mF	paper
C2	.01 mF	"	C10	.01 mF	"
C3	25 mF	{ 25 v. electrolytic	C11	.05 mF	"
C4	.1 mF	paper	C12	500 pF	mica
C5	.05 mF	"	C13	16 mF	{ 500 v electrolytic
C6	.02 mF	"	C14	.1 mF	paper
C7	.005 mF	"	C15	.05 mF	"
C8	.01 mF	"			

Inductors:-

L1 and L2 0.5 H.

Components in Gated Crystal Oscillator - Fig. 28.

Resistors:-

R1	1M.	¼ watt	R16	1M	¼ watt
R2	50K	¼ "	R17	250K	¼ "
R3	10K	1 "	R18	100K	½ "
R4	500K	½ "	R19	51K	2 "
R5	45K	(High Stability)	R20	20K	1 "
R6	45K	"	R21	80K	4 "
R7	15K	1 watt	R22	2K	1 "
R8	470K	½ watt	R23	47K	¼ "
R9	470K	½ "	R24	680K	¼ "
R10	68K	(High Stability)	R25	4.7M	¼ "
R11	68K	"	R26	22K	1 "
R12	1M	¼ watt	R27	25K	1 "
R13	100K	¼ "	R28	470K	¼ "
R14	4.5K	1 "	R29	10K	½ "
R15	1K	variable	R30	100K	½ "

Condensers:-

C1	8 mF	(500 v. electrolytic	C9	8 mF	(500 v. electrolytic
C2	25 mF	25v."	C10	25 mF	25v. "
C3	100 pF	ceramic	C11	100 pF	ceramic
C4	50 pF	"	C12	100 pF	"
C5	50 pF	"	C13	50 pF	"
C6	.5 mF	paper	C14	.002 mF	mica
C7	500 pF	mica	C15	.5 mF	paper
C8	8 mF	(500 v. electrolytic	C16	.01 mF	"

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